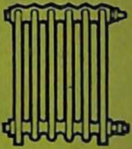
SCIENCE ON THE MARCH

Unit 11

HEATING AND COOLING



68 — 3735
4211
17.5.88

SCIENCE ON THE MARCH

UNIT ELEVEN

HEATING AND COOLING

STATE INSTITUTE
BAN

Polar Photos Ltd.

An eskimo boy goes to school in the Canadian Arctic. He is well protected by clothes which keep the heat of his body from escaping outside. Why is he fairly warm inside an igloo ?

SCIENCE ON THE MARCH

UNIT ELEVEN

HEATING AND COOLING

Philip E. Heafford

General Editor : **Charles H. Dobinson**

LONGMANS

S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B. C. Road

LONGMANS, GREEN AND CO LTD
48 Grosvenor Street, London, W.1
Associated companies, branches and representatives
throughout the world

© Philip E. Heafford 1959

First published in Great Britain 1959
Second impression 1960
Third impression 1963

This unit has been specially written for SCIENCE ON THE MARCH by Philip E. Heafford, M.A., B.Sc., Lecturer in the University of Oxford Department of Education. The general editor of the series is Charles H. Dobinson, M.A., B.Sc., Professor of Education in the University of Reading.

530
HEA

Every photograph in this unit, unless otherwise acknowledged, was taken by Philip E. Heafford.

The first thirteen units of SCIENCE ON THE MARCH are:

.C.E R T., West Bengal
Date 17.5.88
Acc. No. 4211

1. The Air and You.
2. Water and Life.
3. The Weather and the Earth.
4. Life and Food.
5. Health.
6. Energy and Engines.
7. Hearing and Seeing.
8. Electric Currents.
9. Magnets and Electric Power.
10. Earth and Universe.
11. Heating and Cooling.
12. Birth and Growth.
13. Metals and Men.

Made and Printed in Great Britain by Butler & Tanner Ltd, Frome and London

CONTENTS OF UNIT ELEVEN

HEATING AND COOLING

Problem A : WHAT IS HEAT AND HOW IS IT TRANSFERRED ? 8

Question 1. What are the Sources of Heat ? 9
Question 2. What is the Nature of Heat ? 11
Question 3. How does the Transfer of Heat take place ? 13
Question 4. How are Homes and Buildings Heated ? 25
Question 5. How is the Transfer of Heat Prevented ? 33

Problem B : WHAT IS TEMPERATURE ? WHAT ARE THE EFFECTS OF CHANGE OF TEMPERATURE ? 38

Question 1. How is Temperature Measured ? 39
Question 2. What is the Effect on some Substances of a Change of Temperature ? 45
Question 3. What Use do we make of Expansion and Contraction ? 52
Question 4. How do we Compensate for unwanted Expansion and Contraction ? 57

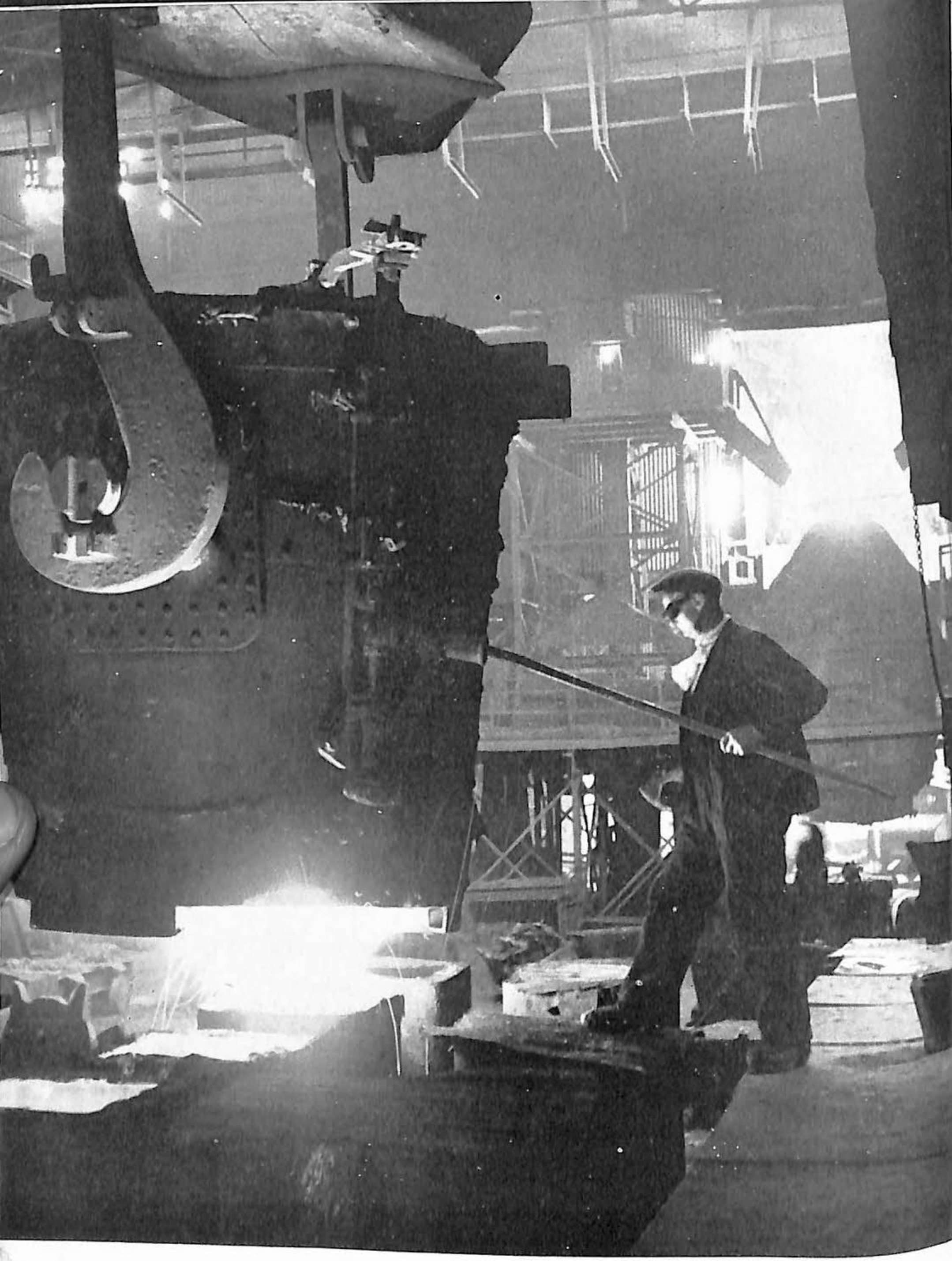
Problem C : HOW IS HEAT ENERGY MEASURED ? 61

Question 1. What is a Unit of Heat Energy ? 61
Question 2. Do all Substances absorb Heat Equally ? 63
Question 3. What Happens when Hot and Cold Substances are brought together ? 67

Problem D : WHAT ARE THE THREE STATES OF MATTER ? 69

Question 1. What Happens when a Solid turns to a Liquid ? 72
Question 2. What Happens when a Liquid turns to a Solid ? 77
Question 3. What Happens when a Liquid turns to a Gas ? 80
Question 4. Can a Liquid turn to a Gas without Boiling ? 81
Question 5. What Happens when a Gas turns to a Liquid ? 82
Question 6. Can Pressure affect the Melting Point or Boiling Point ? 84
Question 7. What Uses can be made of Changes of State ? 87

Notes on the Unit 95



Workington Iron and Steel Co.

FIGURE 1. Steel made by the Bessemer process being poured into moulds. The operator wears tinted glasses over his eyes so that he can see clearly as he controls the flow of molten steel.

Heating and Cooling

WHEN man first learnt how to make a fire and to control it in order to obtain the heat he needed we can say that Science was already on the march.

Today man uses and controls tremendous quantities of heat—he works hard to discover new sources of heat energy, erects large machines to control it, and goes to much expense to conserve it. But, in spite of all his efforts, heat begins to escape as soon as he has made a store of it.

In this Unit we shall consider where heat comes from and how it travels so that we shall know better how to promote or prevent its movement as we wish. For instance, we want to transfer heat to our homes in winter and to prevent the heat inside escaping to the cold air outside; and we want to cool a motor-car engine by transferring heat away from the engine where too much of it would be harmful.

We shall learn how the addition of heat makes some substances increase in size and may even cause them to change from solids to liquids and then to gases. There are many ordinary daily observations that we can make which will help us to understand the effects of heat.

We shall consider in this Unit how heat can be measured. One of the essential instruments we shall use is a thermometer, but this measures temperature and not heat. We must know what temperature is and how it helps us to measure heat, so that we can check the movements of heat as it is controlled and used in our daily life.

Problem A: WHAT IS HEAT AND HOW IS IT TRANSFERRED?

Men believed, many years ago, that heat was a kind of fluid, like a liquid or a gas, which could pass in and out of substances as they were heated and cooled. Then it was found that a hot body was exactly the same weight as the same body when cold. Thus scientists concluded that heat was certainly not matter.

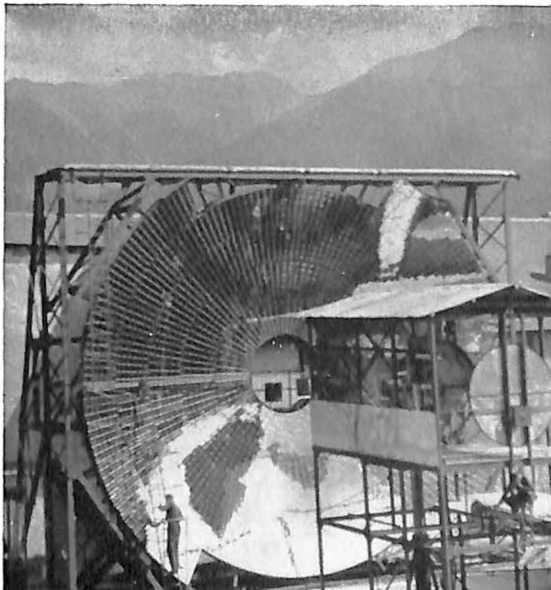
Unit 6 taught us much about energy. We learnt that the steam engine was once the only means we had for making heat do some of our mechanical work. The steam engine is no more than a machine used to convert heat to mechanical energy. In fact the term "heat energy" is often used: it is an energy of a special kind.

When steam engines were made and their working began to be understood, scientists and engineers realized that heat was used to do work, and it was found that the more heat used the more work was done. The energy stored in coal, called *chemical* energy, is released by burning to form heat. The heat boils water in a boiler and produces a store of *potential* energy in the steam under pressure. The steam pushes the piston in the cylinder of the engine, losing its potential energy and creating *kinetic* energy, the energy of movement, in the wheels of a locomotive or in the propellers of a ship. Heat is thus one of the forms of energy.

Question 1. **What are the Sources of Heat ?**

Place an iron poker in a fire and leave it there for a few minutes. Remove it from the fire and we notice that its end is red hot. It feels hot and it gives out heat which we can detect on the surface of the skin. We have learnt not to touch the red-hot end for it will burn us. The burning fire has produced heat which has been transferred to the poker.

There are other ways of producing heat. For example, the human body gets hot as the food consumed is oxidized by the oxygen we breathe in ; the brake shoes of a motor-car rub against the brake drums on the wheels when the brakes are applied and the drums get very hot, especially if used on the long descent of a hill ; an electric lamp filament gets hot when an electric current is passed through it ; the surface of the earth gets hot when the sun shines on it. This last example is of special importance for almost all the energy used by man originally came from the sun. Solar heat energy can be used directly and solar furnaces may one day be of importance.



Illustrated

FIGURE 2. This solar furnace has a curved mirror 34 feet in diameter and is made of 3,500 glass reflectors. The sun's rays focused by this huge mirror on a very small area can heat a substance placed there to 3,000° C.

The methods we have considered of producing heat are really methods of transformation of one kind of energy into another—heat. 1. *Chemical.* The coal or wood of the burning fire combines with the oxygen in the air to liberate heat. This is the chemical process of rapid oxidation. The stored-up energy in food is transformed to heat by the chemical process of slow oxidation in the human body. 2. *Mechanical.* The mechanical energy in the moving motor-car is turned into heat in the brake drums. 3. *Electrical.* When electricity passes along the filament of the lamp, electrical energy is converted into the heat given out by the lamp.

These three transformations use up energy which was previously created by solar energy and then stored in some form or other. Green plants containing chlorophyll use solar energy in the process of making foods. In any given time the quantity of energy absorbed by all the chlorophyll in all the plants on earth is more than one thousand million times greater than the quantity of energy generated by the world's biggest power station. After millions of years these foods decay to form coal, natural gas, and oil. Solar energy on the earth's surface causes evaporation, thus lifting water from the surface of the land and oceans to the skies. Rainfall on high ground finds its way back again to sea-level, and the energy in the falling water can be utilized by man for the production of electrical energy.

There is still another source of heat which is becoming rapidly important and may be the answer to our need for larger and larger supplies of energy. This is the *fission* (splitting) and the *fusion* (combining) of the nuclei of atoms.

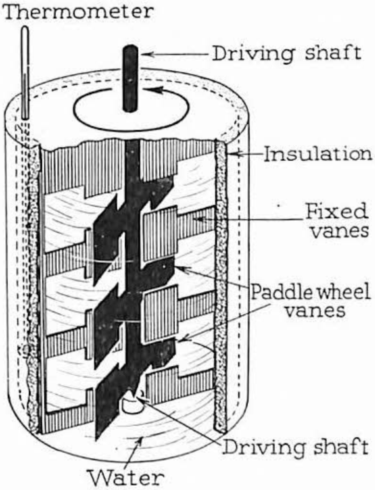
Question 2. **What is the Nature of Heat ?**

According to all the observations we have made so far, heat is a form of energy. How did people learn what heat is ?

Count Rumford, an American colonist, became minister of war in Bavaria. When boring cannon in Munich, he noticed that the metal chips thrown off by the boring tool were exceedingly hot. He surrounded the cannon with water containers and actually boiled the water in them. He thus demonstrated to the scientists of his day that heat had some direct connection with the boring movement. He, in fact, concluded from this that " heat is motion."

It was some years after Rumford's death that a Manchester brewer called Joule established a precise relationship between the quantity of heat produced and the amount of work done by a moving body. He found this relation by churning water with sets of paddle wheels in an insulated container. The original apparatus used by Joule is in the Science Museum at South Kensington. He performed these experiments between 1843 and 1850, and since that time nobody has doubted that heat is a form of energy.

FIGURE 3. A drawing of the apparatus used by Joule for determining the quantity of heat produced by a certain amount of work done. Can you see the vanes of the paddle wheels and the fixed vanes of the container ?



The really important thing that Joule did was to convert different kinds of energy into heat energy in many ways. In each case he found the same relationship, which is usually called *Joule's equivalent.*

From this work there developed the theory known as the *conservation of energy*. This theory states that energy cannot be destroyed, but only changed in form from one kind of energy to another kind of energy.

All matter is now believed to be made up of separate small particles which are continuously in a state of agitation. The energy of motion of these particles is heat. The hotter the particles, the faster they move. This " hotness " is called temperature.

Heat and temperature must not be confused. Temperature is only one factor which determines how much heat a body has. Another factor is the number of particles in the body. Still another factor is the nature of the particle itself. We shall consider again the quantity of heat in a body in Problem C.

SOMETHING YOU MAY CARE TO DO

Half-fill an electric kettle with cold water and switch it on. Make a note of the time the water takes to boil. Empty the kettle, and then fill it again with cold water from the same tap, but this time fill the kettle full. Switch the kettle on, and switch it off when the time you noted before has elapsed. Now how hot is the water ? Obviously you have supplied the same quantity of heat because you used the same kettle for the same time, but the rise in temperature of the water is less. The same amount of heat produced a different rise in temperature (in different quantities of water) : this tells us that heat and temperature are not the same.

Continue with another experiment. Use some of the lukewarm water left in the kettle to half-fill a tin about the same size as a tea-cup. Take six equal sized cubes of ice from a refrigerator and put three of them in the water in the tin and three of them in the remaining water in the kettle. Stir both for a few moments. What do you observe ? If we assume heat is needed to melt the ice, then is there much more heat available in the kettle than in the tin in spite of the fact that the water in both the kettle and the tin were equally hot (same temperature) to begin with ?

Heat is one thing and temperature is another. Temperature is not a reliable indication of the amount of heat available in a body unless we are dealing with the same or identical bodies.

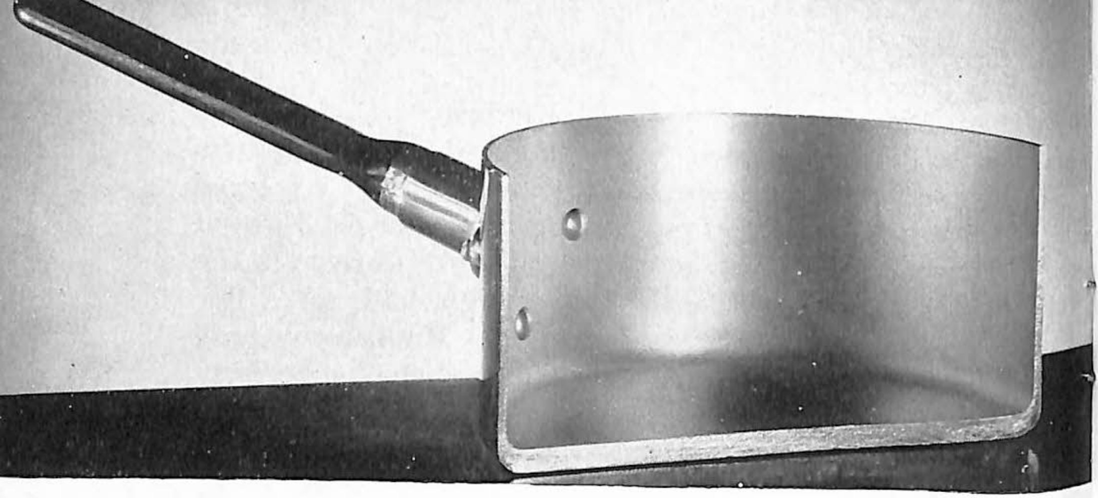
Problem A : **What is Heat and how is it Transferred ?**

Question 3. **How does the Transfer of Heat take place ?**

Heat can be transferred from one point to another in three different ways : *conduction*, *convection*, and *radiation*. Frequently a body gains heat or loses heat by a combination of all three ways.

CONDUCTION

Conduction takes place when heat is transferred from particle to particle throughout the whole of the body without any visible signs of movement at all. Some substances, particularly metals, are good heat *conductors*, whilst others are so poor that we can use them as *insulators* to hinder the flow of heat. Copper, aluminium, and iron are good conductors in that order.

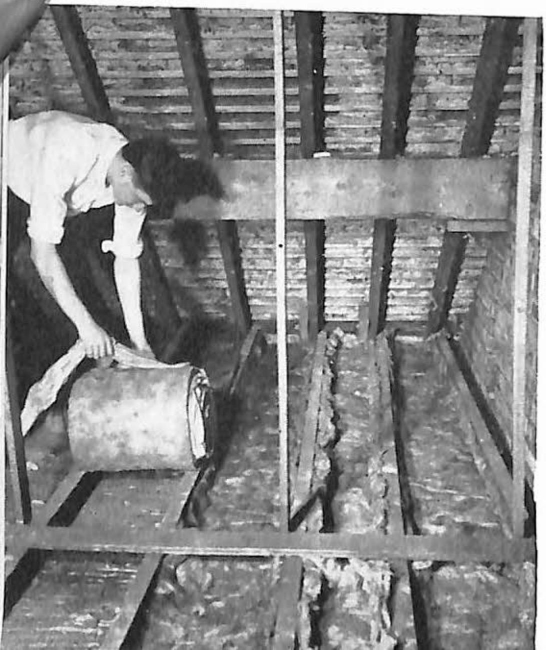


Hague and McKenzie Ltd.

FIGURE 4. A cross-section of a saucepan suitable for use on an electric hot-plate. Why have the hot-plate and the bottom of the saucepan to be perfectly flat ? Why is the bottom of the saucepan thick ?

Asbestos, glass wool, sawdust, wood, fur, wool, and air are poor conductors. Does this explain why saucepans have copper or aluminium bottoms ? Why heating stoves have iron sides, and hot-water boilers are made of iron ? Why soldering irons have copper tips and wooden handles ? Why ceilings are often covered with a layer of glass wool ? Why the fur on animals grows thick in winter, and man wears woollen clothes in the cooler climates ?

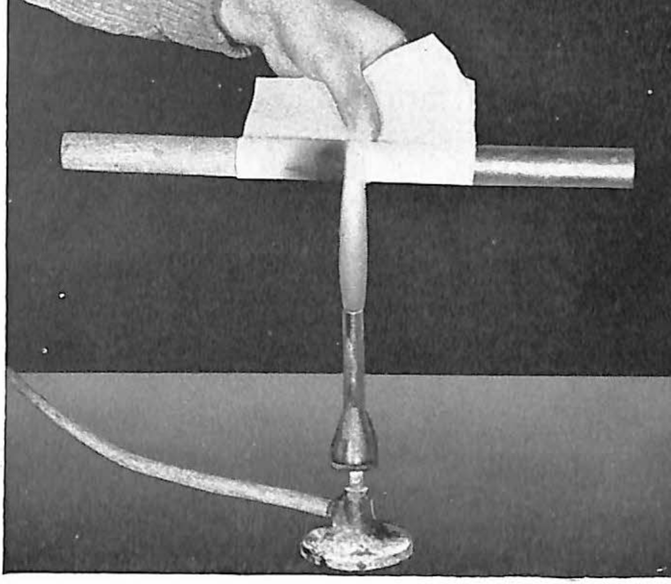
Can you think of other uses of good conductors and good insulators ?



Fibreglass Ltd.

FIGURE 5. This roll of glass wool is being used to cover the attic floor. It forms a layer of still air in its fibres and this prevents heat escaping through the ceiling to the roof.

FIGURE 6. The boy is holding a rod made of wood and metal. On the left is the wooden part and on the right is the metal. They fit together as smoothly as a shaft fits on a spade. The flame heats the paper as much on one side of the junction as on the other. If the paper is held tightly, why does it burn on the wood side and not on the metal side ?



SOME THINGS TO FIND OUT

1. *Which is the better conductor, a metal or wood?* Take a metal tube about 8″ long. Insert in one end of it a length of a wooden broom-handle of the same diameter. You may have to file the wood to get a perfectly smooth rod. Wrap a sheet of paper round the junction. Heat the paper by rapidly moving a flame to and fro near the join of the metal and the wood. Why is the paper not scorched on the side of the metal ?

2. *Which substances are good and which are poor conductors of heat?* For this experiment you will need a number of rods or bars of different substances. Rods of about $\frac{1}{8}''$ diameter will be suitable for this purpose and they should all have the same diameter. Try to get rods of aluminium, copper, iron, zinc, and brass. Cut the rods to the same length, and cover them with melted paraffin wax to give them a thin wax coating. Mount them on a stand so that they all

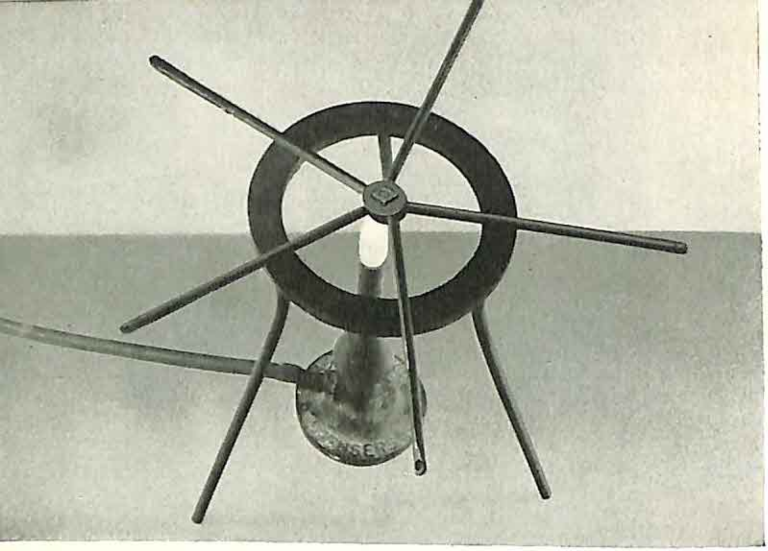
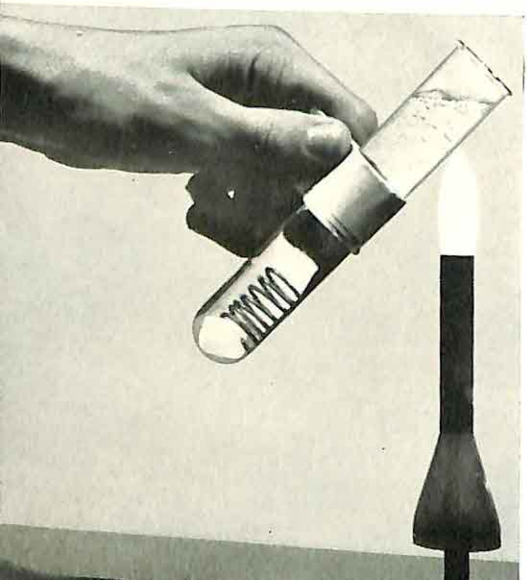


FIGURE 7. How to mount rods of different substances, in order to find out which are the good and bad conductors of heat. Why have you to be careful to place the bunsen flame exactly at the junction of all the rods where a small nut and bolt helps to keep them together ?

touch in the centre as in Figure 7. Light the flame in the centre and arrange it to touch all rods equally. Observe how far the wax melts on each rod. Which is the best conductor of heat ? In your notebook make a list of the substances in order of conductivity.

FIGURE 8. Boiling water and ice together in the same test-tube.



3. *Is water a poor conductor of heat ?* Place at the bottom of a thin-walled test-tube a small piece of ice. Slide down the tube to the ice a coil of solder wire, so as to keep the ice in position. Nearly fill the test-tube with cold water. Heat the water near the top of the test-tube with a small flame. Does the ice melt rapidly ?

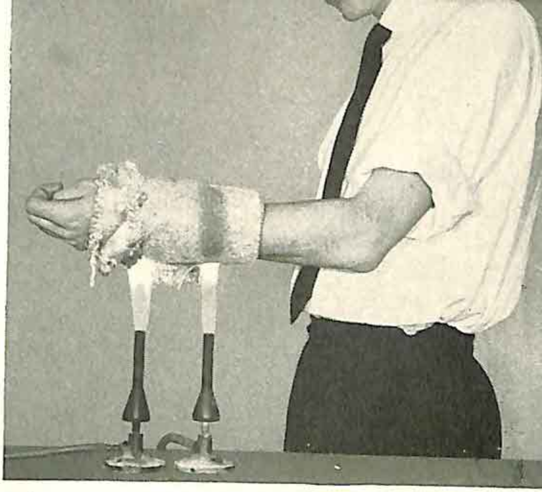


FIGURE 9. This boy's hand is wrapped in an asbestos sheet. After a short time he feels only a moderate heating effect. The insulation of asbestos makes it a valuable protection against fire.

4. *Can asbestos protect you from being burnt by naked flames?* If you can get a sheet of asbestos you can wrap this around your hand as the boy is doing (Figure 9) and direct the fierce flame of a bunsen burner at the asbestos. If you can only get narrow strips of asbestos you might be able to tie some strips round your finger and then perform the same experiment on your finger. In your school laboratory is there a large asbestos blanket which can be thrown around a person whose clothes catch on fire? Do you know how to use it in case of an emergency?

CONVECTION

Convection is the conveying of heat by the circulation of heated portions of a liquid or a gas. Heat causes a fluid (liquid or gas) to increase in size and thus to become less dense. The cooler, denser fluid pushes the

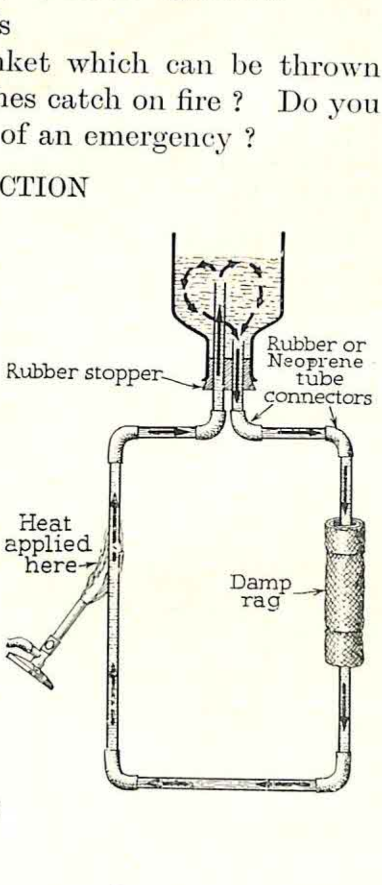


FIGURE 10. Why does the water circulate in the tubes as shown by the arrows? Does the rag damped with cold water help the circulation of convection currents?

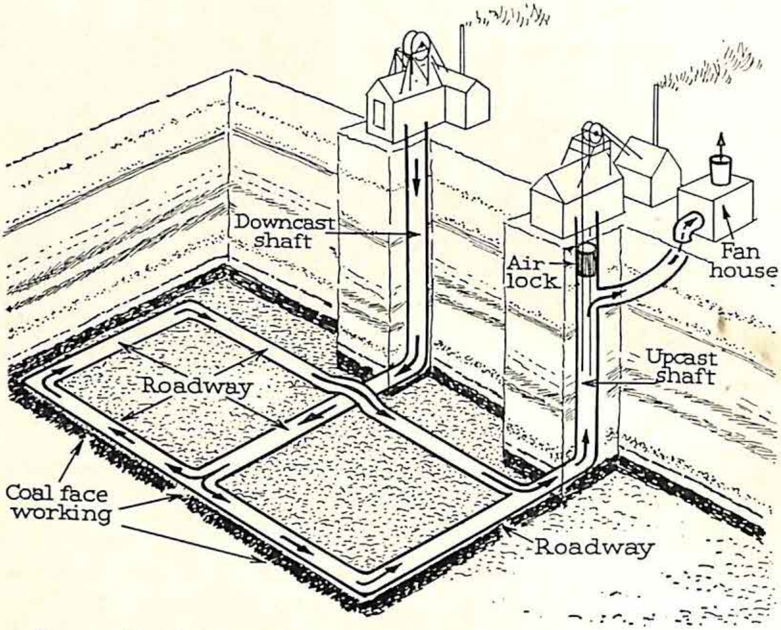


FIGURE 11. Diagram of the flow of air through a coal mine. The hot, foul air rises through the upcast shaft while cold, clean air descends the downcast shaft to the miners at the coal face. Why is there an air-lock at the top of the upcast shaft through which cages carrying coal have to pass ?

warmer, lighter fluid upwards. These movements are called convection currents. The winds are convection currents caused by the heat of the sun. Convection currents circulate fresh air through the workings of a coal mine. In Figure 11 you can see by the direction of the arrows the actual course taken by the air. It descends the downcast shaft, passes along the roadways to the coal face, and from there it returns along more roadways to the upcast shaft. The natural thermal convection current is assisted by fans near the top of the upcast shaft.

SOME THINGS YOU MAY CARE TO DO

1. *To study convection currents in a liquid.*

Cut off the top of a glass bottle and smooth the sharp edges with a glass file. Your teacher will show you how to do this, using a short length of an electric heating element or a red-hot poker and some engine oil. Cut lengths of glass tubing and connecting rubber or neoprene tubing, and set up the apparatus shown in Figure 10. Make a solution in water of a few drops of some soapless detergent and then stir in it a little aluminium powder. Pour enough of this solution into the bottle reservoir until it covers the top tube. Heat one side of the apparatus, and cool the other side with a damp rag. Convection currents can be observed passing steadily up and down the tubes.

2. *To study convection currents in air.*

(*a*) Cut a number of slots in a circular disc of thin tin or card. Bend the teeth to form a fan and mount this on a bent wire. Hold it over a candle flame so that the rising hot-air convection currents can cause it to revolve. The paper spiral will spin in the same way. Use the disc to find the positions and strengths of the convection currents in a room above a heated stove or hot plate, and above a lighted electric lamp or a burning candle.

(*b*) Take a cardboard shoe box and turn it on one side. Mount two wide glass lamp chimneys through holes in the top side of the box. Light a small candle

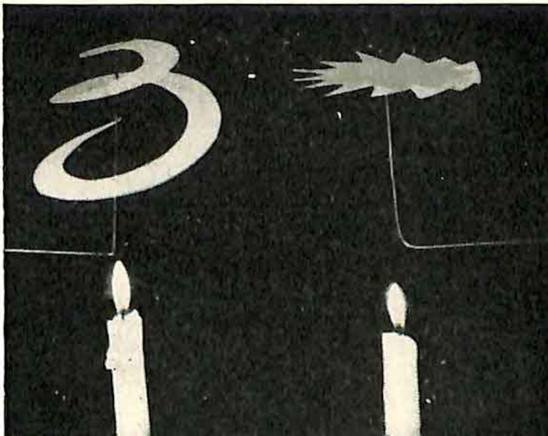


FIGURE 12. Instruments for finding the position and strength of convection currents in air.

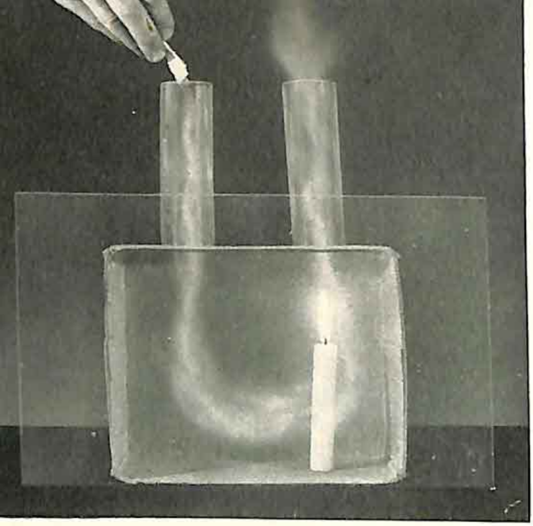


FIGURE 13. The smoke in this box follows the path of the convection currents of the air. What would happen if the glass fitted well and the down-draught chimney were closed ?

and place it in the box beneath one chimney. Close the front of the box with a sheet of glass as shown in Figure 13. Put a small piece of smouldering rag above the other chimney. The smoke will circulate through the box showing the path of the air convection currents.

RADIATION

Some solid, liquid, or gas has to be present for the two ways of transferring heat so far studied—conduction and convection. But a body can receive and give off heat through an empty space. For example, we can feel the warming effect of the sun's rays although we know there is nothing at all in the space between the sun and the earth. This is the method of heat transfer known as *radiation*. We think it travels in waves in the same way as light travels.

SOMETHING YOU MAY CARE TO DO

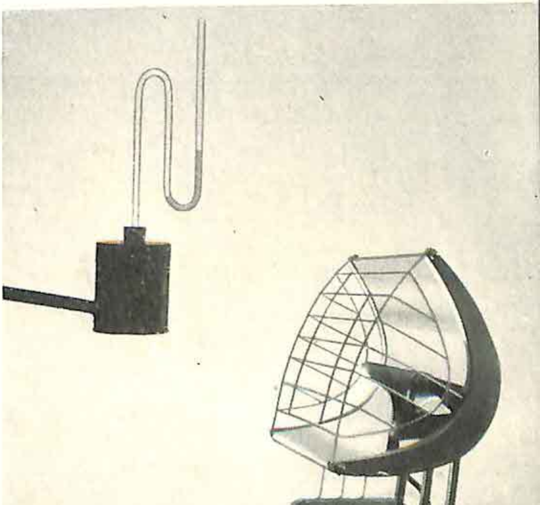
Take a tin with a well-fitting lid. Blacken the tin in the smoky flame of a candle. Through the lid insert a rubber bung. Through the bung push an S-shaped glass tube. In the bend of the tube put some coloured water. Around the tin fix a handle. You have now made a radiation detector. Hold it about one foot away from the heating coil of an electric fire and switch on. Note two things—the colour of the heating coil and the movement of the water in the S-bend. You should notice that for several seconds before the coil becomes dull red your detector is being struck by radiation and you too will feel this as heat. This heat is due to invisible *infra-red* waves which form a large part of heat radiation. Gradually the coil becomes redder and brighter, and as it does so the radiant energy striking the detector and your hand becomes greater. In fact, the amount of heat lost from a body by radiation increases as the body becomes hotter than its surroundings.

S.C.E.R.T., West Bengal
Date 17.5.88
Acc. No. 4211

When radiation strikes a body, the heat may be *reflected* (obeying the same laws as light). Or the heat may be *transmitted* through the body (as light passes through a glass sheet). Or the heat may be *absorbed* by the body (as light is absorbed by a piece of black material). The absorption of radiation depends on the nature of the surface of the absorbing body. Dark, rough surfaces are good absorbers and poor reflectors. Shiny, light-coloured surfaces are poor absorbers and good reflectors.

Bodies whose surfaces are good absorbers of radiation are also good radiators, and similarly poor absorbers are poor radiators.

FIGURE 14. Infra-red heat is invisible. This detector shows that heat is radiated from the electric fire before the filament becomes red hot.



530
HEA

S.C.E.R.T., West Bengal
Library

If you know these facts then you will be able to answer questions like these. Why do tea- and coffee-pots have shiny surfaces ? Why is a motor-car radiator (the real one inside the bonnet) painted dull black ? Why do men wear light-coloured suits in the summer ? Why does a piece of dark metal quickly sink into snow or ice when the sun shines on it ? Why at the sea-coast does a breeze often blow away from the land at night ? Why do fruit growers take precautions against frosts on cloudless nights in spring ?

SOME THINGS YOU MAY CARE TO DO

1. *To study the reflection, transmission, and absorption of radiation.*

(*a*) Mount a lamp from a car headlight in a stand, connect it to a battery, and switch on. Place the back of your hand or your radiation detector one foot away from it. Can you detect the radiation ?

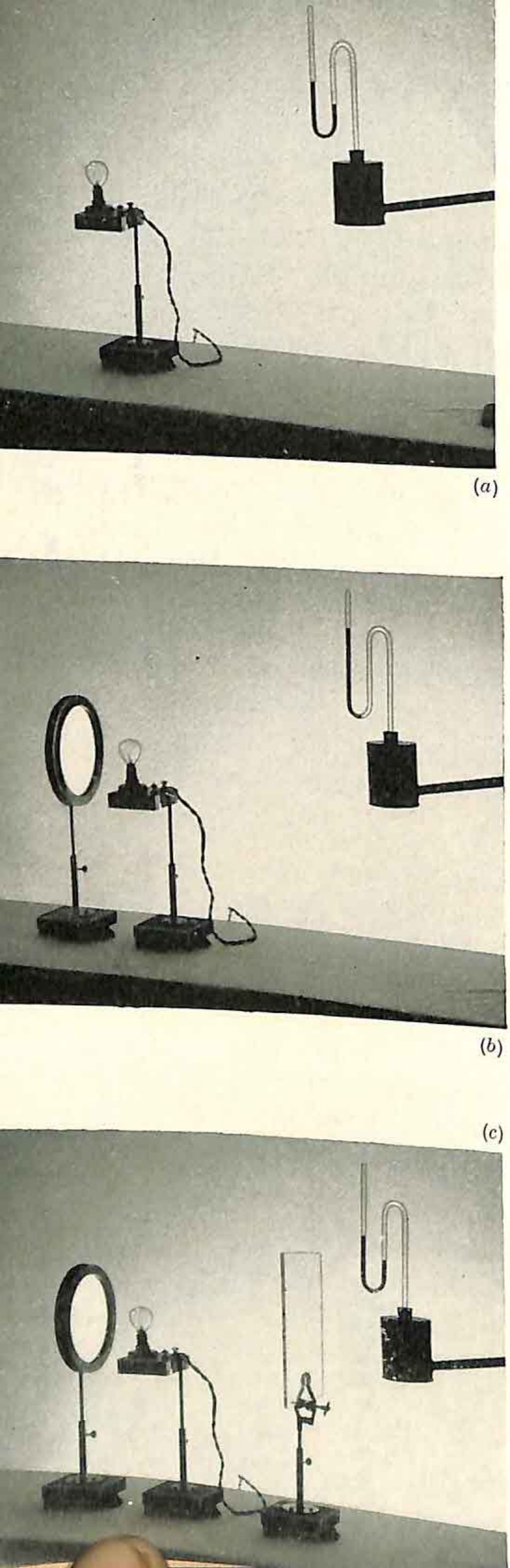


FIGURE 15.
(*a*) How the headlamp is mounted.
(*b*) How to place the reflector.
(*c*) How to place the glass sheet.

(*b*) Place a curved mirror reflector behind the lamp so that a good number of rays are reflected forward. Can you detect the heat of the radiation this time ?

(*c*) Place in front of the lamp a glass sheet. Does this glass cut off the radiation ?

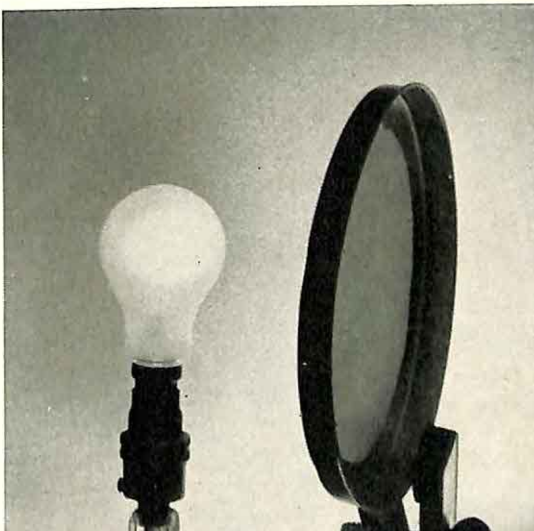
Do these experiments confirm that radiation can be reflected, transmitted, and absorbed ? Can you feel the radiation in front of the headlight of a motor-car when it is switched on ?

2. *To determine which of several surfaces is the best absorber of radiation.*

Cover one surface of a number of tin lids of the same size with different paints—glossy white, dull cream, red, aluminium, and with lampblack from the smoke of a candle. Behind each tin lid paste some heat-sensitive paper. You can make this by soaking duplicating paper in a solution of 1 part of calcium chloride, 1 part of cobalt chloride, and 20 parts by weight of water, and allowing to dry. This paper is a pale pink colour when cold and pale blue when warm.

Place each lid one after the other 4″ away from a 150-watt, 240-volt lighted electric lamp and time how long it takes for the sensitive paper on the side away from the bulb to turn blue. Which is the best absorbing surface ? Which is the poorest absorbing surface ? You can perform this same experiment on a clear day by using the heat radiation from the sun. Be careful, for some dull black objects can get very hot in the sunshine.

FIGURE 16. Testing the absorbing power of a surface.



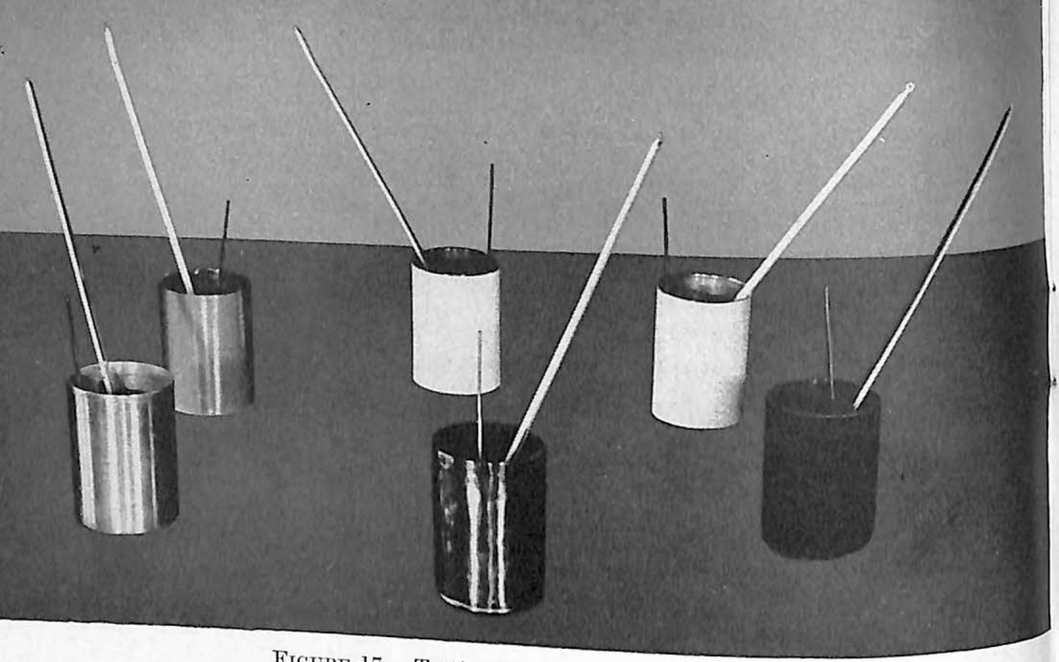


FIGURE 17. Testing the radiating powers of several different surfaces.

3. *To determine which of several surfaces is the best radiator of heat.*

Take several tin cans of the same size and cover their surfaces in the same way as you did in the last experiment. In each can put a thermometer and a wire stirrer. Fill each can to the same height, about three-quarters full with boiling water. Place the cans on a table away from draughts and any sources of heat. Stir them, and write down the temperature of the water in each can after 5, 10, 15, 20, 25, and 30 minutes. Which is the best radiating surface? Which is the poorest? Is the order in which you place the surfaces for good radiating power the same as the order for good absorbing power? Are good radiators good absorbers?

Question 4. **How are Homes and Buildings Heated ?**

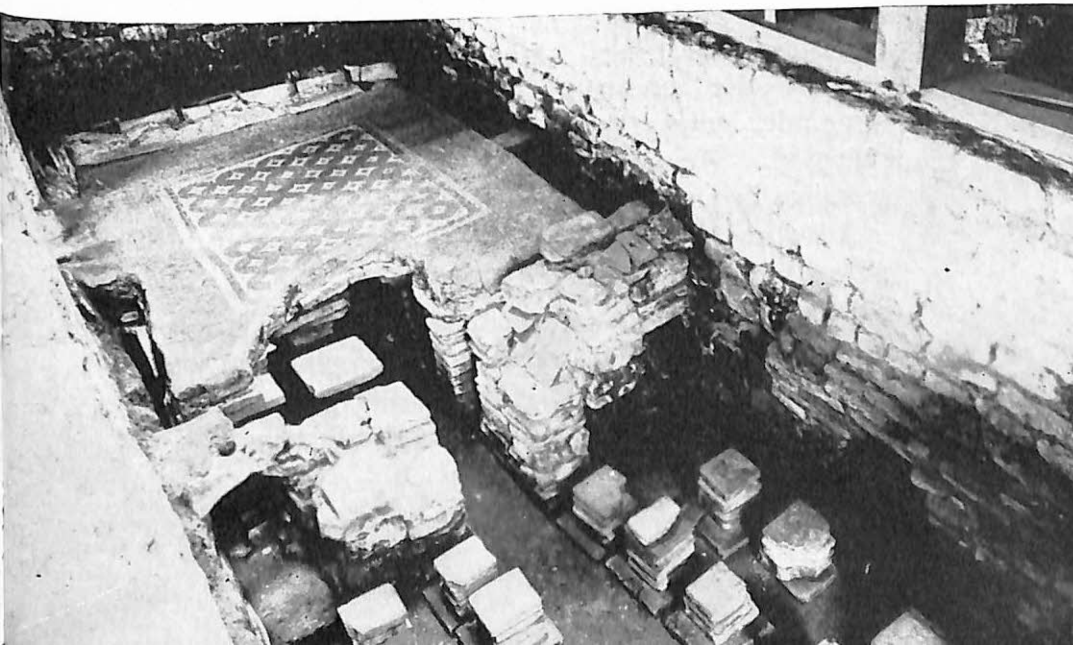
One of the simplest ways of heating a building is by the use of hot-air convection currents.

Nearly two thousand years ago the Romans built houses in England with " central heating " provided in this way. Streams of hot air and waste gases from a fire were carried under the floor and upwards by convection behind the walls of a room. The floor and the walls conducted the heat into the room, where hot-air convection currents were set up.

In some modern homes air is heated by conduction through the walls of a furnace and from there it is circulated by convection. A large air jacket surrounds the furnace. The heated air rises through wide tubes and is led in this way to where it is needed in the

FIGURE 18. This photograph, taken in a Roman villa at Chedworth in Gloucestershire, England, shows part of the mosaic floor of one of the rooms. The floor was raised on piles of square tiles to allow the hot air to pass freely beneath it.

George Roper



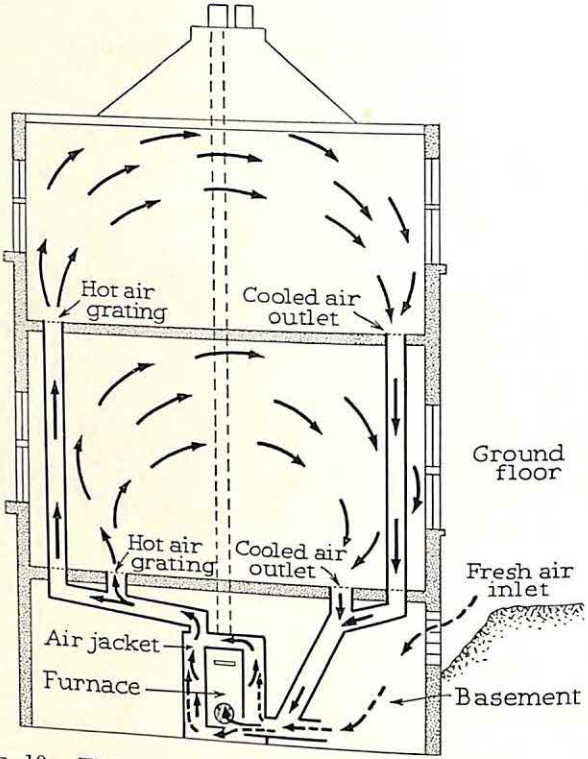


FIGURE 19. This diagram shows how air heated by a furnace circulates throughout the rooms of a house. Why is the furnace placed in the basement? Why is a fresh-air inlet needed?

building. The cooled air descends and some of it is used in the combustion in the furnace, while the remainder enters the air jacket at its base and is reheated. The distribution is controlled by slotted gratings in the floors of the rooms.

All three ways of transferring heat are involved when buildings are heated by hot-water systems. The most important is convection because it causes the circulation of the hot water in the pipes and of the hot air in the rooms. Radiation and conduction are involved in heating the water in the furnace and the

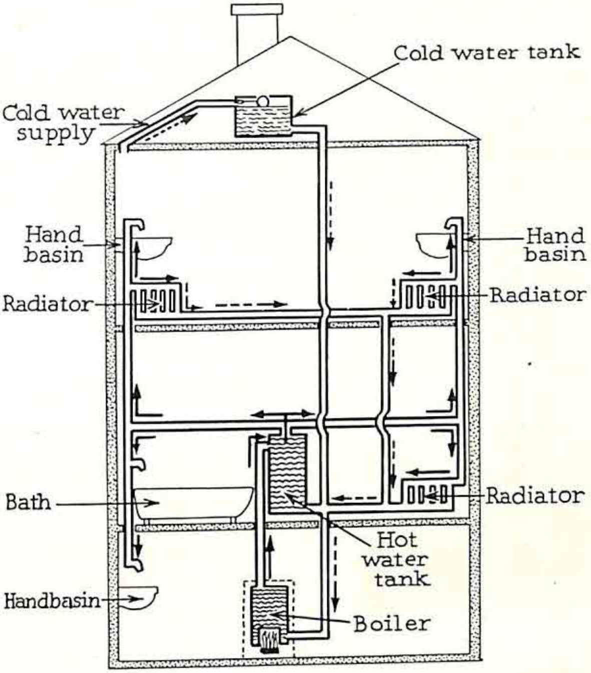


FIGURE 20. A hot-water heating system in a house designed to supply radiators, a bath, and hand basins. Why is it desirable to install the hot-water tank above and close to the boiler ?

air in the rooms. Examine Figure 20 carefully and find out how one radiator can be turned off without affecting the others. Can you see how hot water is drawn away for the hand basins and the bath ? Notice the position where the hot-water and the cold-water pipes are joined to the boiler, and to the hot- and cold-water tanks. Why is there a small air valve at the top of a radiator ?

Radiators supply the heat for the rooms, but this is not really a good name for them as they only radiate a small amount of heat. You can judge the radiation given out by means of your radiation detector. They set up convection currents in the air and it would be

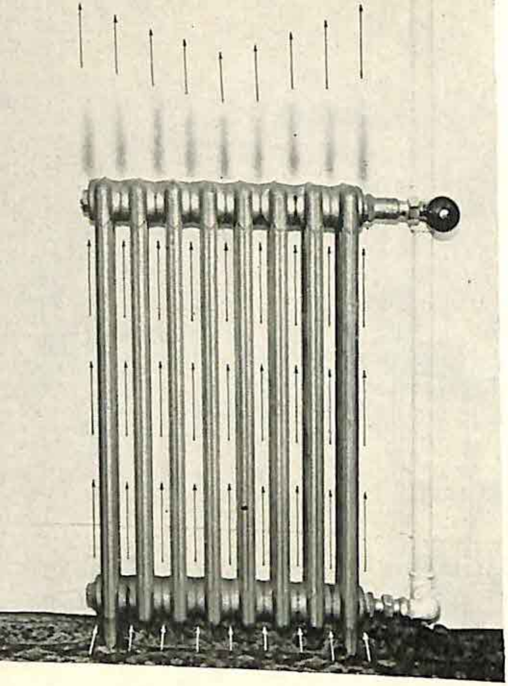
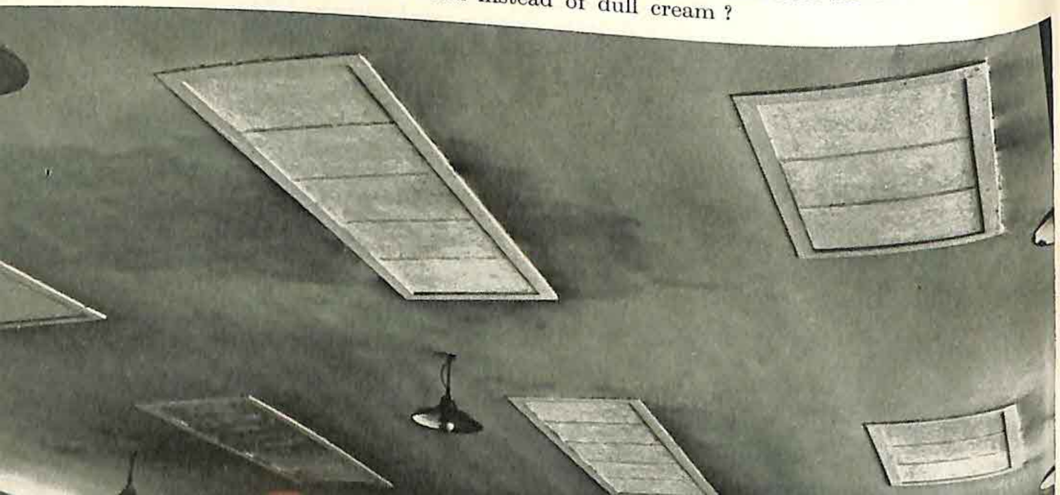


FIGURE 21. Why would a convector be a more accurate name for this? The arrows and also the dirty wall marks show the paths taken by the convection currents.

better to call them *convectors* because more heat is convected from them than is radiated from them. Heat is conducted from the hot water inside through the iron to the air in contact with the "radiator" on the outside. The air is heated by this contact and then begins to circulate by convection currents. Why are there frequently dirty marks on the walls above radiators?

There are several types of real radiators of radiant energy used for heating purposes in homes and buildings. There is the type which is heated by hot water,

FIGURE 22. Radiators installed in the ceiling of a school laboratory. Even on cold days the windows are left open and the pupils feel the warmth of the radiation. Would there be more radiation if the colour of the radiator were black instead of dull cream?

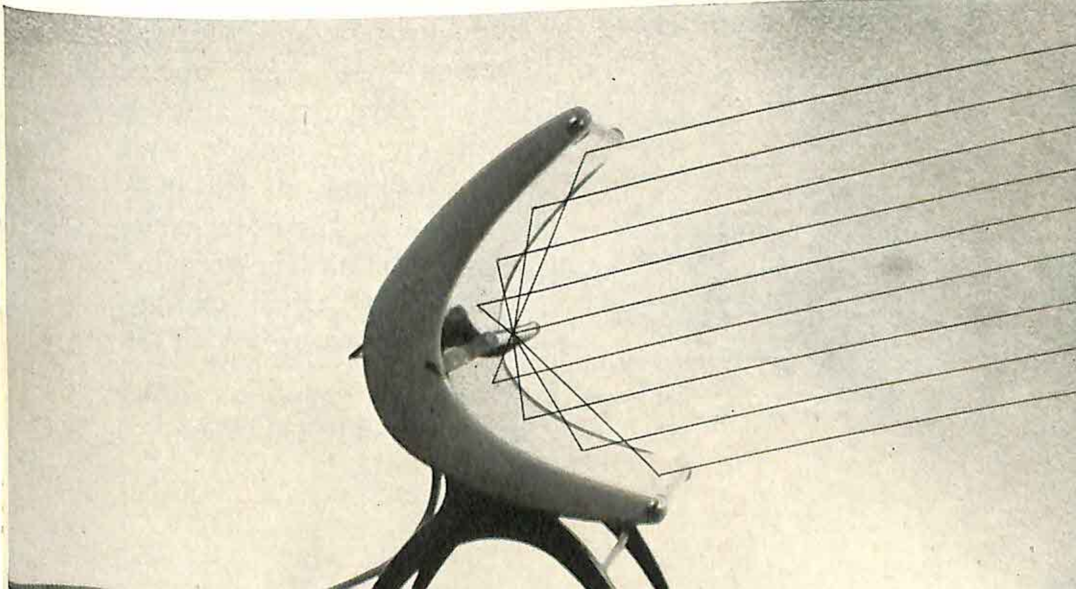


steam, or electricity and is installed in the walls or ceilings of rooms. The essential condition here is that its temperature should be as high as possible and not far removed from that of boiling water. These radiators give out more heat by radiation than by convection and therefore they can be placed anywhere in the room. On the other hand convectors must be placed near the floor to cause convection currents to flow.

Another type is the electric radiator fire which is light and convenient and can be adjusted to send its beam of radiation in any desired direction. Notice the shape of its parabolic mirror reflector. Copy the shape of the curve on a piece of paper and then draw the position of the heating bar. You will find, if you draw accurately, that all the radiation, after correct reflection in the reflector, will travel in a parallel beam. That is why a cross-section of the reflector is a parabola and not an arc of a circle.

Fires of solid fuel in open grates and gas fires require chimneys for the disposal of waste gases. This

FIGURE 23. A modern electric radiator fire. Why is the heating bar placed at the focus of the parabolic mirror reflector ? The safety guard has been taken off so that the thin black lines representing the heat rays can be drawn in clearly.



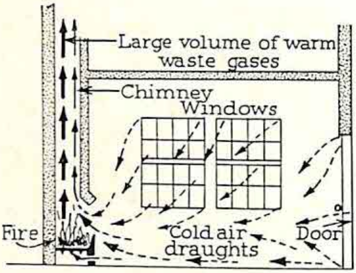


FIGURE 24. An open fire produces cold air draughts in this room. Why is much of the heat derived from the fuel wasted in this kind of fire ?

produces an added complication because much cold air from outside must enter the room to supply oxygen for the combustion of the fuel and then the large volume of warm waste gases is lost up the chimney. The open coal fire, although pleasant to look at, is most wasteful. Not only is much heat lost through the chimney but a lot of the carbon in the fire is unburnt, because it either forms soot in the chimney or it escapes into the air outside to create dirty fogs and to blacken the buildings in towns and cities.

The cold air entering a room from outside produces cold draughts. That is why when you are sitting in front of a coal fire your face gets warm and your back is cold. These cold draughts across the room can be prevented if an opening is provided near the base of the fire for the entry of the cold air. Such an arrangement is shown in Figure 25. These open fires heat the room mainly by radiation. Some heat is conducted through the bricks of the chimney stack and this heat remains in the room. Where the chimney stack is built on the outside wall of a building all the heat conducted there is completely lost into the open air.

Solid fuel slow combustion stoves use very little air

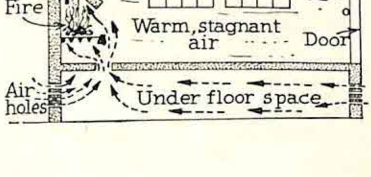


FIGURE 25. An open fire and no cold air draughts in this room.

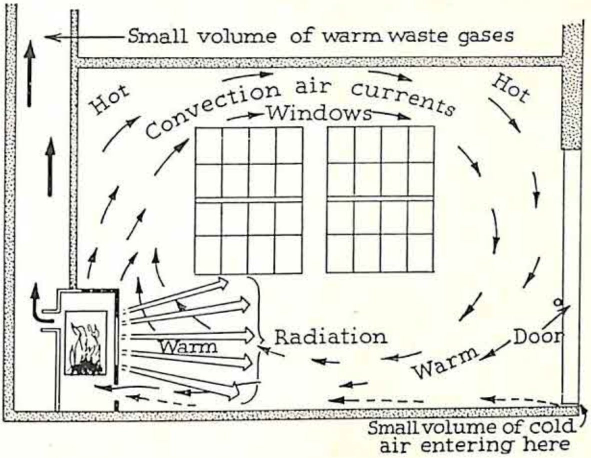

Small volume of warm waste gases
Hot
Convection air currents
Windows
Hot
Warm
Radiation
Warm
Door
Small volume of cold air entering here

FIGURE 26. A solid fuel slow combustion stove installed in a room. Why is this type of heating the most efficient way of using solid fuel ?

and they give out the greatest amount of heat for the fuel they consume. They heat a room mainly by convection currents although there is a little radiation.

SOME THINGS YOU MAY CARE TO DO

1. *Build a model hot-water heating and supply system.* You should look once more at Figure 20 because you are about to make a model of that hot-water system. Figure 27 shows you how you can do this using glass T-tubes, various lengths of glass tubing, and rubber or neoprene connections. The boiler is a large flask, the hot-water tank is a wide glass tube, and the cold-water tank is a glass bottle whose base has been cut off (see page 19). Fill the system with the aluminium powder and detergent solution (see page 19). You must clear any air bubbles which become trapped by tilting the whole system. You can mount it vertically either by means of clamps and stands or by using a number of Terry clips attached to a large board. Heat gently and

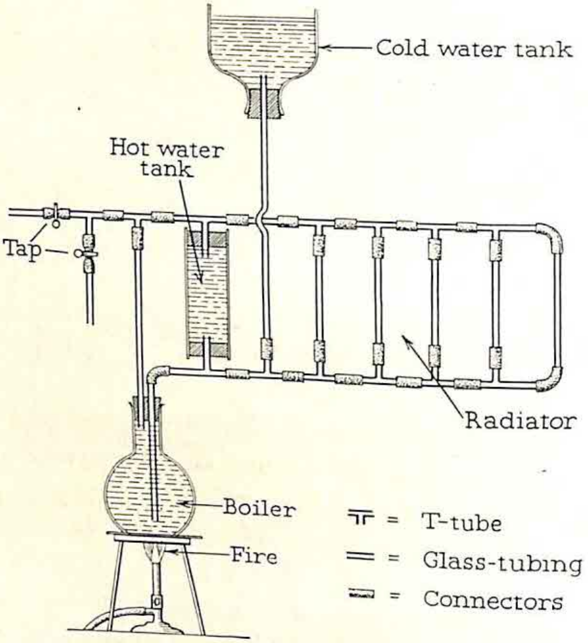


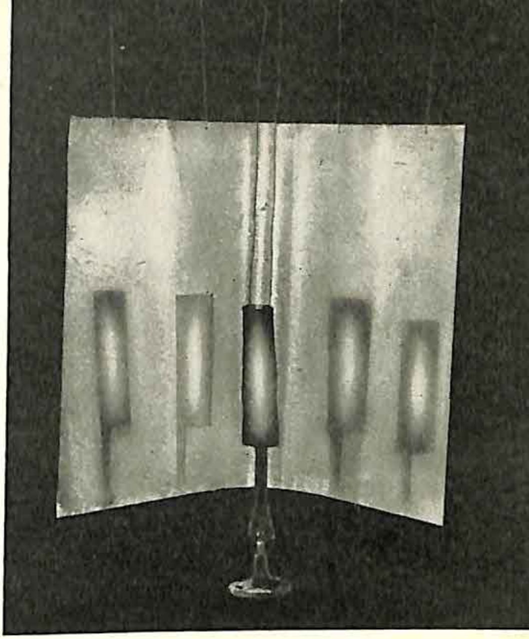
FIGURE 27. How to assemble a model hot-water system of a house.

observe the convection currents formed. As you draw water off by opening the spring clips (taps), you must replace more cold water in the cold-water tank.

2. *Build a model reflector or radiator fire.*

How to build an electric reflector fire was described on page 58 of Unit 8—Electric Currents. You can improve on this model by using a larger sheet of tin or aluminium and bending it in the shape of a parabola. You can mount it on wood blocks. The heating element can be made in many ways. You can use a lighted electric lamp, or a burning candle, or a heated iron wire gauze bent in the form of a cylinder and erected over a burning gas flame. Adjust the exact position of the heating element and the reflecting parabolic sheet mirror so that you get a wide beam of radiation thrown off.

FIGURE 28. A model reflector or radiator fire. The sheet of tin shown in this photograph was not bent into the shape of a perfect parabola because four separate reflections of the heated wire gauze can be seen. The reflections formed by a good parabola all merge into one another to produce one wide image which covers the whole width of the tin. If the tin reflector is well polished, does it get hot? Use your radiation detector to find the exact position of the beam of heat radiation.



Question 5. **How is the Transfer of Heat Prevented ?**

The problem here is to apply in reverse, as it were, the principles we have already learnt about the transfer of heat.

To heat by conduction we found we should use good conducting materials. To stop the transfer of heat by conduction we must remove the conductors altogether or use materials that insulate.

To hinder the transfer of heat by convection we want to reduce the space in which convection currents can occur or remove the fluids which convect.

To hinder the transfer of heat by radiation we want to use shiny bright reflecting surfaces of a light colour.

Homes and buildings can be insulated so that they retain warmth in winter and keep cool in summer by paying attention to these three methods of heat transfer.

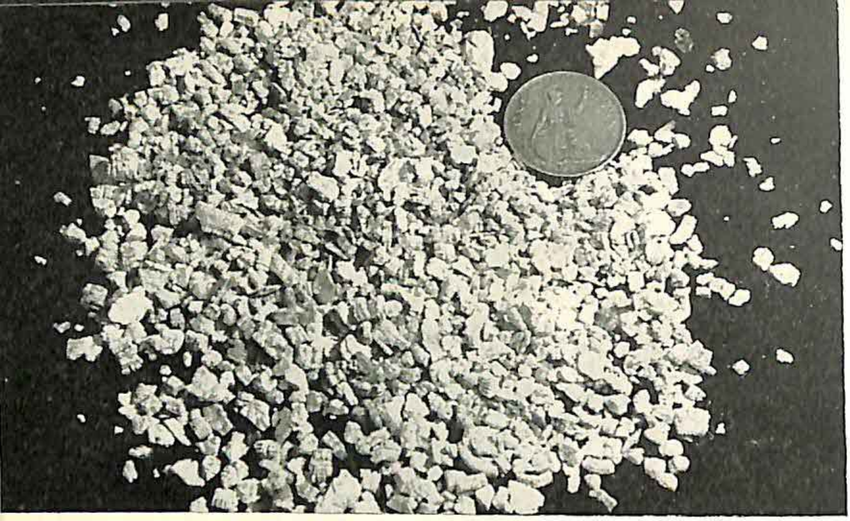


FIGURE 29. A heap or layer of these small pieces of exploded mica contains numerous very small air pockets and forms an excellent insulating material. The penny helps you to judge the size.

Conduction is prevented by putting above the ceilings a layer of glass wool (Figure 5) or loose asbestos (Figure 26, Unit 4). Convection is reduced by filling dead air spaces between the outer and inner walls with some insulating material having only small air spaces, such as small pieces of cork or exploded bits of mica (Figure 29), and by installing double windows. Radiation is reduced by fitting underneath the roof sheets

FIGURE 30. The layer of paper, shiny on both sides, fixed in the roof of this house reflects the heat radiation back to the rooms. Why does it also prevent excessive heat in the upper rooms on sunny days ?

J. H. Sankey and Son Ltd.

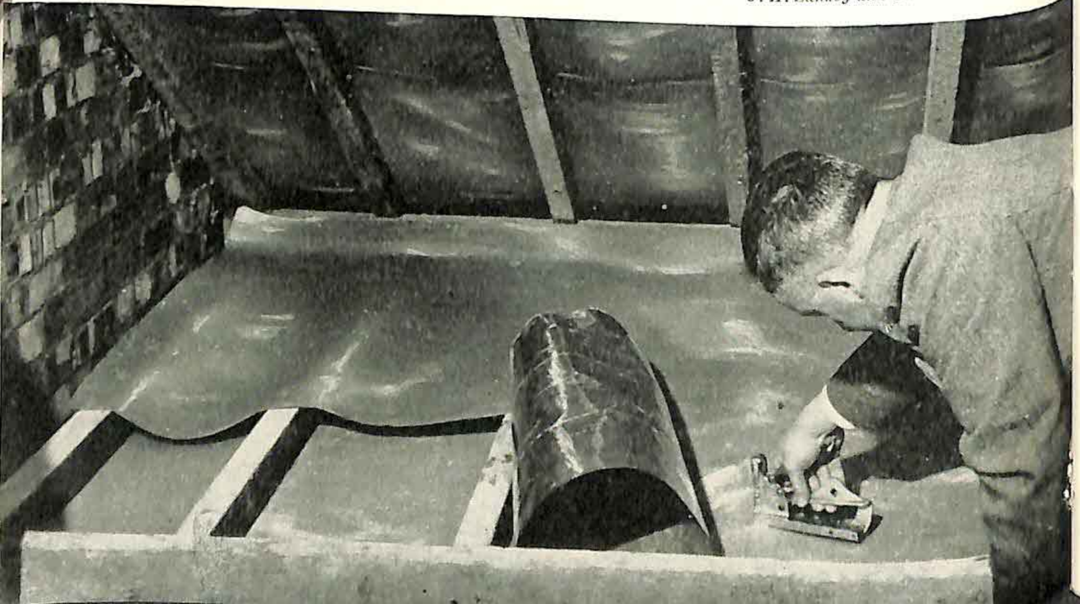
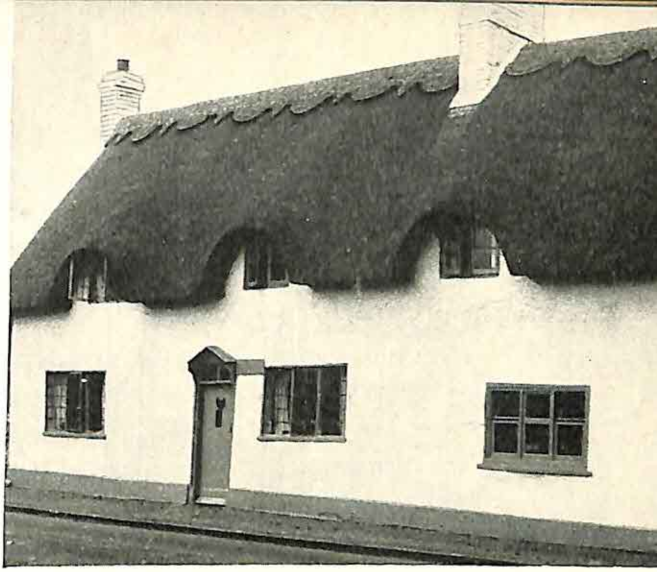


FIGURE 31. The white paint keeps this house warm in winter and cool in summer. Why is the thatch on the roof a good insulator ?



of paper or hardboard covered on its faces by a reflective layer of shiny aluminium foil (Figure 30), and by painting the exterior of the house white.

It has been estimated that 50% of the heat losses in a house occur through the walls and roof, 25% through the doors and windows, and 25% through the entrance of cold air by the doors and windows.

Refrigerator cabinets have to be well insulated to prevent the heat from outside penetrating to the food inside. A thick layer of insulating material is fitted all round the food compartment and on the door. Why must the door be well closed? Why is the freezing unit placed near the top of the food compartment ?

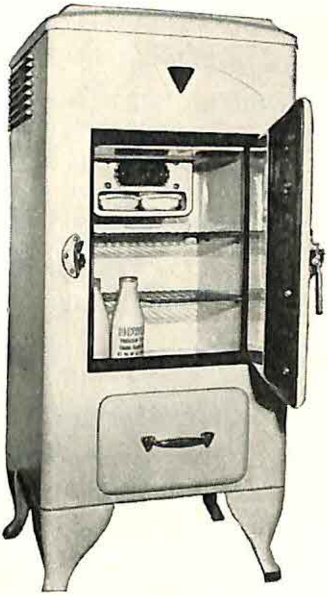


FIGURE 32. An electric refrigerator. Why is the best position for making ice in the ice tray just *below* the freezing unit ? Why has it a thick door ?

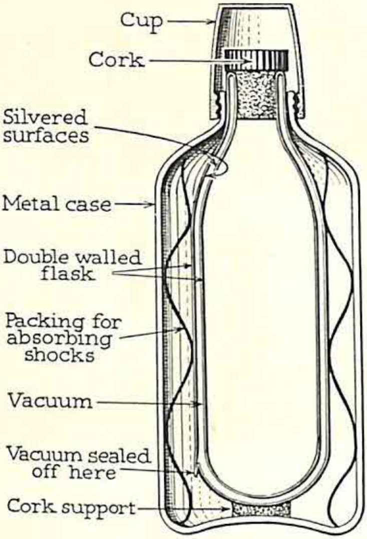


FIGURE 33. A vacuum flask keeps hot things hot and cold things cold. Why does a bigger flask, if it is filled completely, do this more efficiently than a smaller flask ?

The vacuum flask or "thermos" bottle is an interesting example of almost complete prevention of the transfer of heat. A vacuum is created in the space between the double walls of the bottle. Thus the absence of anything in this space prevents heat losses or gains by conduction and convection. The only way heat can be transferred is through the neck and cork of the bottle, and cork is a poor conductor of heat. The inside surfaces of the bottle walls are silvered so that heat radiation is reduced to the absolute minimum.

SOME THINGS TO THINK ABOUT

(1) What fact is true about one method of heat transfer that does not apply to the other two ?

(2) Why are hollow bricks often used in building construction ?

(3) Why do woollen clothes keep us warm ?

(4) Why is a coil of wire often used for the handle of a poker ?

(5) Steam pipes, hot-water tanks, and electric cooking ovens all have to be insulated. What materials are used for these purposes and how are they applied ?

(6) Why does a thick aluminium saucepan feel colder than a wooden table when both have been in the same room for a long time ?

(7) Why can you crawl across the floor of a smoke-filled room when you would be choked if you stood upright ?

(8) Why is it dangerous in extremely cold climates to touch metal objects with bare hands ?

(9) Though air is a better insulator than wood, why is sawdust used as an insulating material ?

(10) Why is it especially difficult to insulate the boiler of a steam locomotive. How is it done ?

(11) Why is it often cooler in valleys than on neighbouring hill sides on a still summer night ?

(12) Why is a tall chimney built for a factory boiler which uses natural convection currents to provide the air draught for its fire ?

(13) Make a sketch of a motor-car engine and radiator and mark on it with arrows the directions in which the convection currents should flow.

(14) Explain how smoke is pushed up a chimney and not sucked up.

(15) Why does snow melt more rapidly on a well-trodden footpath than on the ground near the path ?

(16) Why is ground frost unlikely on a cloudy night ?

(17) What advantage do birds gain by puffing out their feathers on a cold day ?

(18) How are polar explorers protected from frost-bite ?

(19) Why does a farmer make a " bed " of straw for his animals in winter ?

(20) Sometimes leaves fall on a snow surface. Why after several days of sunshine have they fallen to the bottom of a hole in the snow ?

Problem B: WHAT IS TEMPERATURE? WHAT ARE THE EFFECTS OF CHANGE OF TEMPERATURE?

Pick up a piece of iron and hold it in your hand. Does it feel hot or cold? If it has been lying outside on a cold winter's day it feels cold: heat passes from your hand to the iron. We say then that the iron is at a lower temperature than your hand. If it has been lying in the hot sunshine it feels hot: heat passes from the iron to your hand. We say then that the iron is at a higher temperature than your hand. If the iron feels neither hot nor cold, it is at the same temperature as your hand. Heat flows from the hotter body to the cooler body, that is, from the body at the higher temperature to the body at the lower temperature. In fact the direction in which the heat flows, either to or from your hand, is determined by the relative temperatures of your hand and the piece of iron.

SOMETHING YOU MAY CARE TO DO

Prepare three basins of water—one hot, one lukewarm, and one cold. Put one hand in the hot water and one hand in the cold water for about two minutes. Withdraw rapidly both hands and place them both in the lukewarm water. Your hands will tell you they are experiencing different sensations—one will suggest that the lukewarm water is hot whilst the other will suggest that it is cold. Your hands are really *comparing* the temperatures and not *measuring* them. The lukewarm water is hotter than the cold water and your hand tells you so correctly. But we can easily be deceived by our sense of touch. We need a more reliable scientific instrument than our hands if we want to *measure* temperature—something which will do this with certainty every time it is needed.

Question I. **How is Temperature Measured ?**

The instrument used for measuring temperature is a *thermometer*. The expansion of a liquid is the principle commonly used in thermometers designed to tell us ordinary temperatures. If you examine a thermometer you will find that there is a liquid (usually mercury or coloured alcohol) in a small bulb at the end of a long narrow tube on which some marks are scratched. Some of the liquid is in a fine bore in this tube. As the temperature rises, more of the liquid from the bulb expands along the bore. The number of the mark which the liquid reaches on the scale tells us the temperature of the bulb.

Fahrenheit was the surname of the first man to use mercury in a thermometer and he marked the lowest temperature he could reach (by mixing ice and salt together) with the number 0° and the temperature of the human body with the number 96°. If, however, two temperatures easily observed—the melting point of ice and the boiling point of water, called the *fixed points* of a thermometer—are marked 32° and 212° the body temperature turns out to be 98·6°, not 96°.

Celsius was the name of a man who made another scale, using 0° and 100° as his fixed points and then

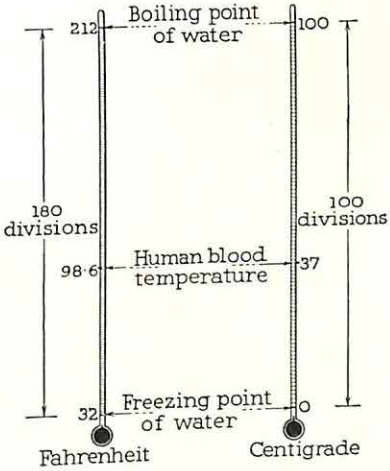


FIGURE 34. The Fahrenheit and the Centigrade temperature scales. On both scales the two fixed points and the correct temperature of the human body are marked.

dividing the range of temperature between them into 100 parts. Hence this is commonly called the *Centigrade* scale (*centi* means one hundredth part).

Scientists all over the world use the Centigrade scale because they like its simplicity, but some English-speaking nations still use the Fahrenheit scale outside the laboratory. This means that we often have to change from one scale to another. You will see by looking at Figure 34 that 180 divisions called *degrees* on the Fahrenheit scale equal 100 degrees on the Centigrade scale. Therefore you can understand how we obtain this equation :

$$\frac{F - 32}{C} = \frac{180}{100} = \frac{9}{5}$$

Human body temperature is found to be 98·6° F. (What does F. stand for ?) What is this temperature on the Centigrade scale ?

Using the equation

$$\frac{F - 32}{C} = \frac{9}{5}$$

then

$$\frac{98{\cdot}6 - 32}{C} = \frac{9}{5}$$

or

$$9C = 66{\cdot}6 \times 5$$

or

$$C = 37^\circ$$

Therefore the temperature of the human body is 37° C. Can you change these temperatures to the other scale : 20° C., 12° F., 75° C., and − 40° F. ?

Mercury thermometers have many uses in the home. In order to make fudge or toffee, the mixture is stirred and heated to a precise temperature of 240° F. or 250° F. respectively. If you wish to liquefy some granulated honey, you must slowly warm it in water and then keep it for some time within the limits of

140° to 145° F.: it does not liquefy at a lower temperature, and at a higher temperature it loses some of its fine qualities. When you prepare the water to bath a baby, the water should be heated to about 98·6° F. or 37° C. All these temperatures are conveniently read on a mercury thermometer.

SOMETHING YOU MAY CARE TO DO

To draw a graph which will help you to convert quickly temperatures from one scale to another (° C. to ° F. and ° F. to ° C.).

Take a sheet of graph paper which has at least 100 small divisions along one side, and at least 180 small divisions along the other. Mark the scales as in Figure 35. Draw with a ruler a straight line between the melting point of ice (0° C., 32° F.) and the boiling point of water (100° C., 212° F.). You can now read off as you wish any temperature on either scale. How can you make a similar graph to read temperatures below 0° C. and above 100° C.?

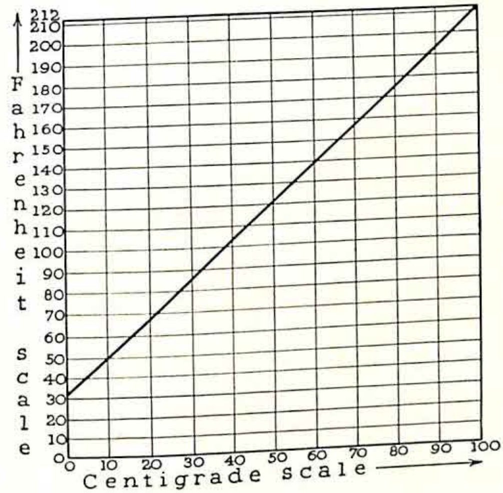


FIGURE 35. A Fahrenheit–Centigrade scale conversion graph.

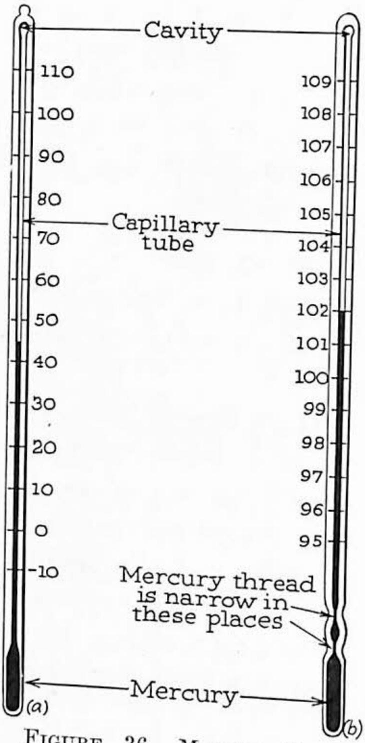


FIGURE 36. Mercury thermometers, (*a*) domestic, with degrees marked on the Centigrade scale, (*b*) clinical, with degrees marked on the Fahrenheit scale.

A special form of mercury thermometer is the *clinical* thermometer used for measuring the temperature of the human body. This is made so that it has a short enlarged scale between about 95° F. and 108° F. because body temperatures vary little. The mercury has to register the highest point reached when it is in the patient's mouth and then not fall when it is removed in order to take the reading. This is done by making a kink or narrow section in the bore of the tube above the bulb. This prevents the mercury from running back when the bulb is cooled so that the maximum reading can be retained and read at leisure. The thermometer has to be shaken vigorously to make the mercury return to the bulb before the next reading.

Alcohol thermometers are used in the polar regions because alcohol does not freeze until a low temperature (− 112° C.) is reached, whereas mercury freezes at − 39° C.

Alcohol is also used in a self-registering maximum and minimum thermometer. The mercury present in this thermometer is there to push the small iron pointers. A small and feeble spring is attached to each pointer to prevent it moving when the mercury moves away. A magnet can nevertheless pull the pointer back to the mercury once the readings have been taken. Where do you often find one of these thermometers? Why is it there?

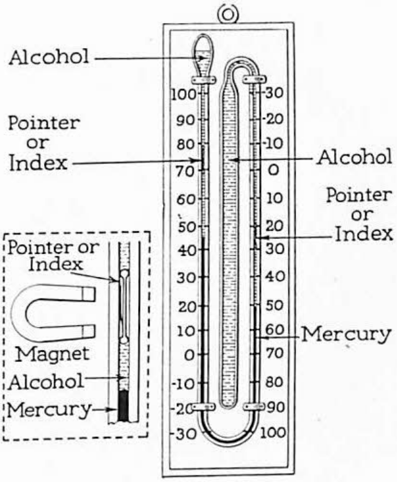


FIGURE 37. An alcohol maximum and minimum thermometer. How are the maximum and minimum temperatures registered? How is the thermometer reset? Why is one bulb half filled with alcohol?

There are other ways of measuring temperature. One very common way is to take advantage of the different expansions of two metals. The two metals, such as brass and steel, are riveted together to form a *bimetallic strip*. As the temperature rises the brass, with the greater expansion, pushes round the steel and thus bends the bimetallic strip. This motion is transferred to a pointer which travels over a scale marked in degrees C. or F. We call this a bimetallic thermometer. It is robust and unbreakable. The motion of the bimetallic strip may be used to regulate some heating or cooling equipment by turning an electric current on or off. When used in this way it forms a *thermostat*. Look at the electric iron on page 56.

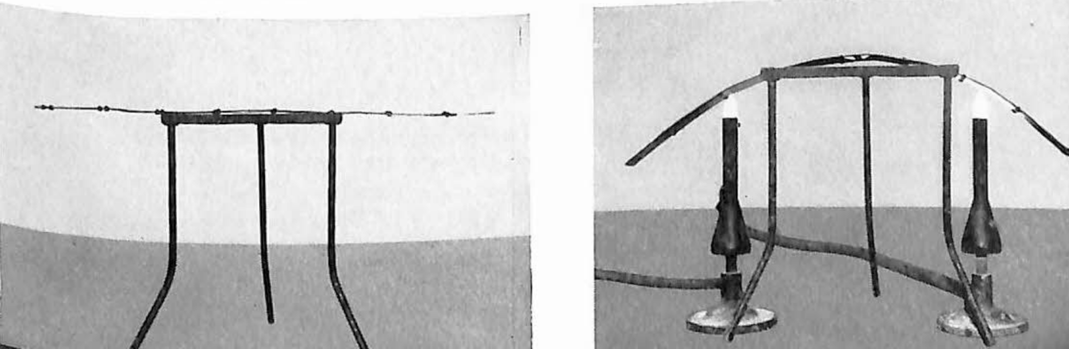


FIGURE 38. These photographs show the same bimetallic strip before and after heating. Brass is on the outside of the curve and steel is on the inside.

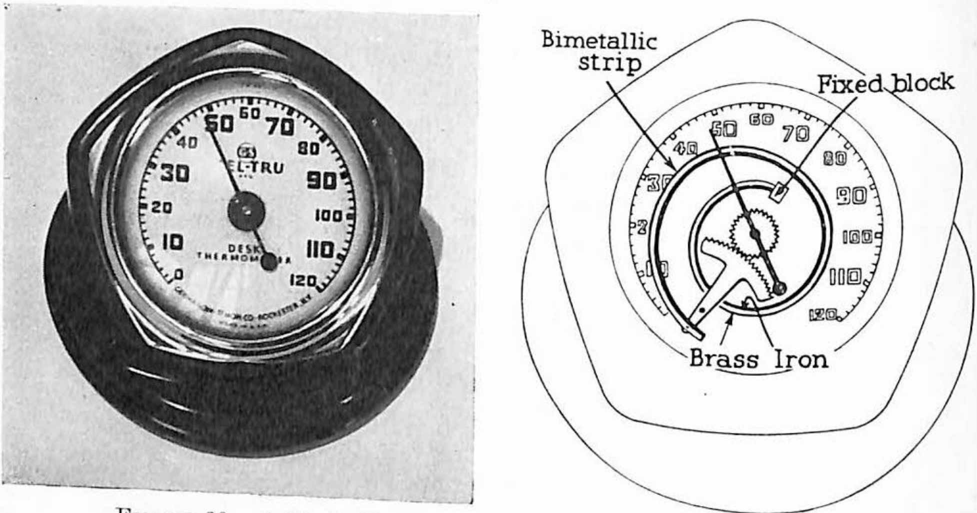


Figure 39. A bimetallic thermometer and a diagram which shows how it works. The long bimetallic spiral attached to the fixed block winds and unwinds moving the ratchet about its pivot and thus turning the gear wheel and its pointer.

A continuous record of temperature is often needed. The instrument which is made for this purpose is the *thermograph*. This contains a bimetallic strip, a recording ink pen, and a rotating drum. Where do you expect to find these instruments?

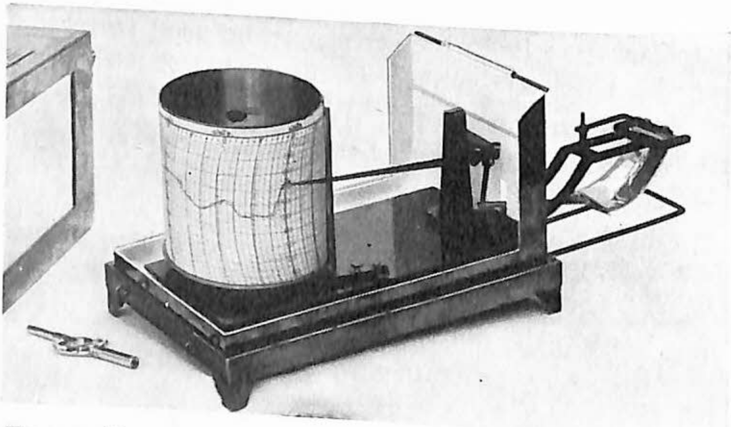
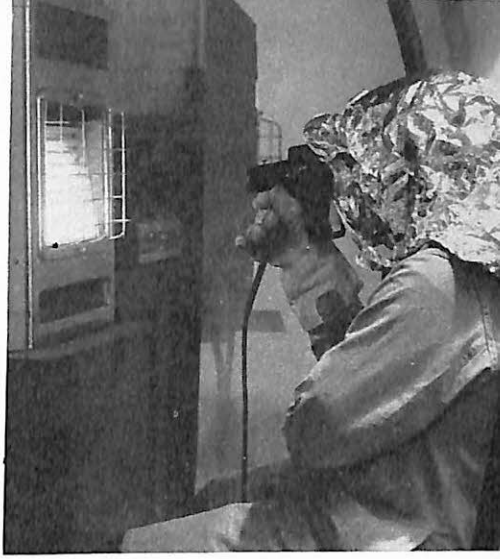


Figure 40. A thermograph. Can you see the curved bimetallic strip on the right and the graph of temperature already recorded?

The temperatures of molten metals, furnaces, pottery kilns, and the exhaust gases of aircraft engines are so high that none of the thermometers so far discussed could measure them. For these high temperatures *pyrometers* are used. Some determine the temperature by observing the colour of the heated material and others use the electrical changes which take place when a circuit of one or more wires is heated.



Keystone Press Agency Ltd.

FIGURE 41. This man, with his head covered with thin aluminium foil to reflect the heat, and wearing asbestos gloves, is measuring the temperature of a gas fire by means of a pyrometer.

Question 2. **What is the Effect on some Substances of a Change of Temperature ?**

SOLIDS

Heat causes solid bodies as well as liquids and gases to expand. When man builds an engine, a machine, a bridge, and many other things too, he must allow for the expansion that may take place as the temperature changes. Our daily lives are very much concerned with the effects of the *expansion* and the *contraction* of different substances. Any one solid expands or contracts by the same amount for the same rise or fall in temperature, but different solids expand

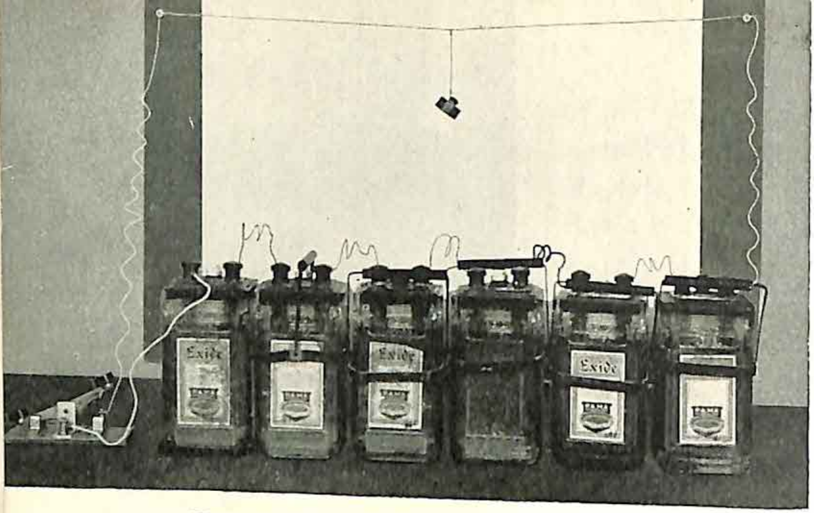


FIGURE 42(a). Cold eureka wire stretched between two nails with a small weight attached in the middle to keep it taut.

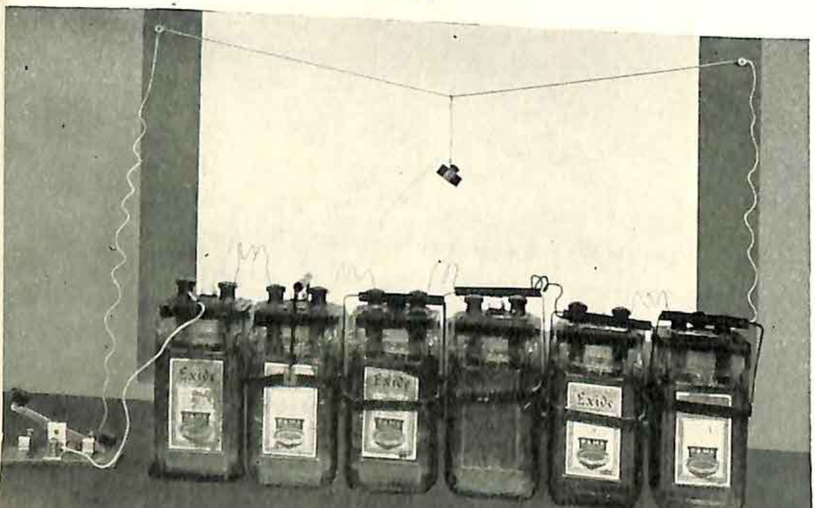
different amounts. The amount of the expansion and contraction is very small indeed and usually it is difficult to see unless we make use of some special device for the purpose.

SOME THINGS YOU MAY CARE TO DO

1. *To observe the expansion of a long wire when heated by an electric current.*

Mount 30″ of No. 28 S.W.G. eureka wire between two nails and hang a weight in the middle of the wire.

FIGURE 42(b). The same eureka wire heated by the passage of an electric current. Could this apparatus be used to measure the strength of the electric current ?



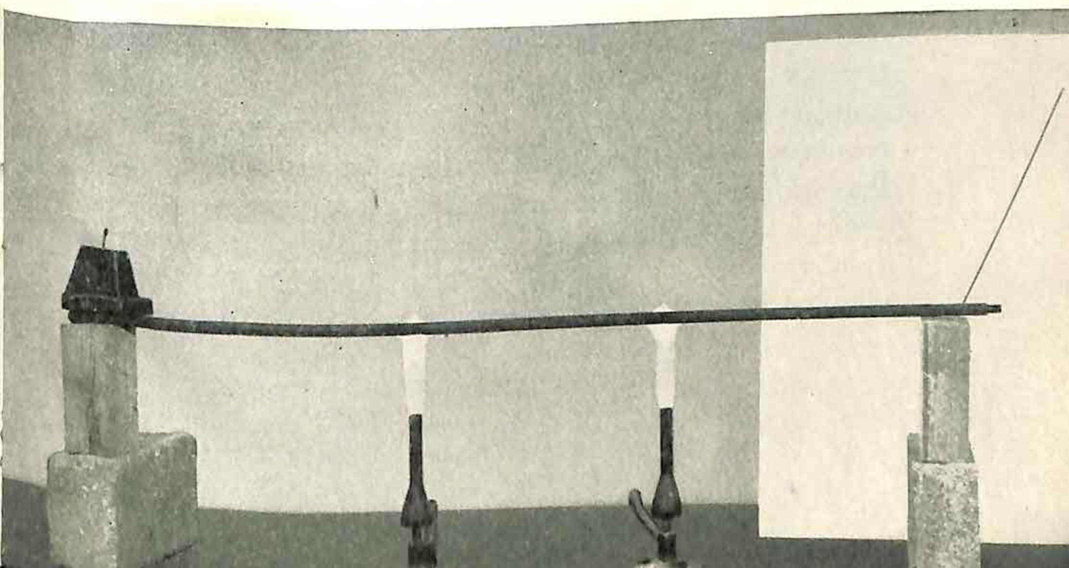
Connect the two ends of the wire to a switch and a fully charged motor-car battery, or six 2-volt accumulators joined in series. Switch on the current for about 10 seconds and observe the movement of the wire as it is pulled down by the weight, then switch off. Why must you switch off so soon ?

2. *To observe how a metal bar expands and contracts.*

Clamp one end of an iron bar (about 2′ or 3′ long) and let the other end roll freely on a round thin knitting needle to which a straw pointer has been attached. Heat the metal bar and observe the movement of the pointer and also note how difficult it is to see any movement of the unclamped end of the bar. Does the expansion increase as you heat the bar more strongly and thus raise its temperature ? Does the bar return to the same position when it has completely cooled down again ? Using a longer bar and more flames to heat the bar, would you expect a greater expansion ? Repeat the experiment, using a brass or aluminium bar instead of an iron one. Do you observe a greater expansion this time ?

These experiments show us that the amount of

FIGURE 43. This photograph shows you how you can magnify the very small expansion of a metal bar so that you can observe it easily.



expansion of a metal bar depends on the length of the bar, the material of which it is made, and the rise in temperature.

Why does a thick glass tumbler or bowl break when boiling water is poured in it? The boiling water in contact with the glass causes the glass on the inside of the tumbler to expand rapidly. The glass on the outside of the tumbl does not get warm quickl for glass is a bad conduct of heat and thus it does no expand at the same time. A great strain is set up between the two sides of the tumbler, and the glass cracks. You cannot prevent this uneven expansion if the outside remains cold whilst the boiling water is poured in. This is therefore one of the things you should not do. Why does a thin-walled glass tumbler not break?

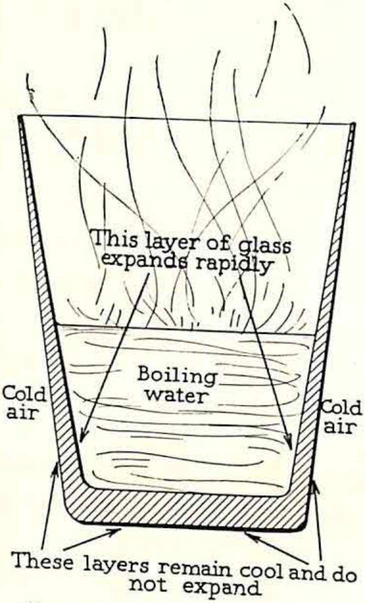

This layer of glass expands rapidly
Boiling water
Cold air
Cold air
These layers remain cool and do not expand

FIGURE 44. How can you pour boiling water into a thick glass tumbler without breaking it?

We have discovered that by adding compounds of boron to the mixture from which glass is made, we can produce a glass (such as Pyrex) which expands and contracts very little on heating and cooling. This means we can make glass cooking basins and bowls that will stand most normal temperature changes without cracking. Pure silica or quartz vessels, often used in laboratories, can actually be heated red-hot and then plunged in water without cracking.

LIQUIDS

Liquids expand and contract to a much greater extent than do solids. You can easily see the expansion and contraction of a liquid in a thermometer.

The expansion and contraction of water is unique. Water at 0° C. contracts as it is heated until 4° C. is reached, and then it expands as the temperature rises. This means that every given mass of water has its smallest volume and greatest density at 4° C. We do not know why this is so, but because this happens the water at the bottom of a lake in winter is usually at 4° C. even when there is ice (at 0° C.) on the top of the lake. In this way the aquatic life at the bottom of lakes survives without difficulty during a severe winter. When water at 0° C. freezes it expands considerably and becomes much lighter. Thus the ice that forms floats easily on the water which still remains at 0° C.

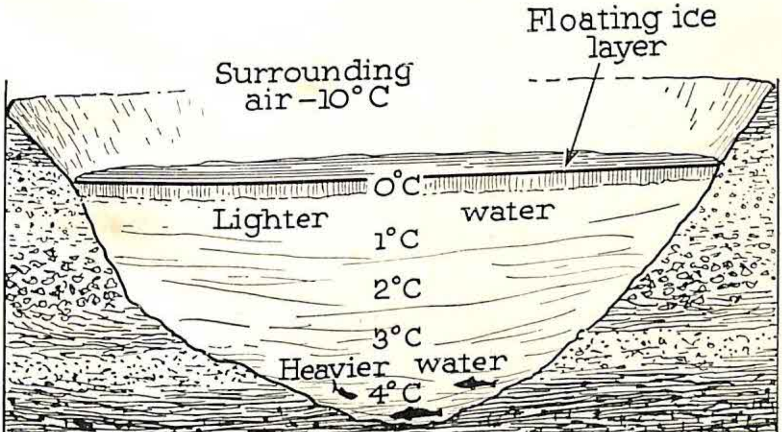


FIGURE 45. This diagram shows the temperatures that you might record on a cold day in winter. Why is it unlikely that the temperature at the bottom of a fresh-water lake will fall below 4° C. ?

SOMETHING YOU MAY CARE TO DO

To observe the expansion of different liquids.

Fill three medicine bottles : one with water, one with paraffin, and one with methylated spirits. Fit each with a cork and a fine glass tube. Bring the liquids to the same level in each tube. Immerse all three bottles in a basin of hot water. The difference in the expansion of the liquids is shown by the rise of the liquids in the three tubes.

GASES

Gases expand when heated. All gases expand by the same proportion, and this is about 20 times that of mercury or 8 times that of water.

Flour is mixed with water, salt, and yeast to make bread. The mixture called dough is left to " rise " in a warm place. The yeast plant produces carbon dioxide gas in little pockets throughout the dough. When this is baked in the oven the carbon dioxide and the steam from the water expand, as all gases do, to produce a large number of holes in the bread.

SOME THINGS YOU MAY CARE TO DO

1. *To observe the expansion of air.*

Fit a cork and a long glass tube into a large flask. Invert it so that the end of the glass tube dips into some water. When you warm the flask with your hands, the air inside expands and bubbles out through the water. When you remove your hands, the air contracts and water is pushed up the tube by the atmospheric air. You will find that the water level in the tube is very sensitive to temperature changes because air has a large expansion for a small rise in temperature.

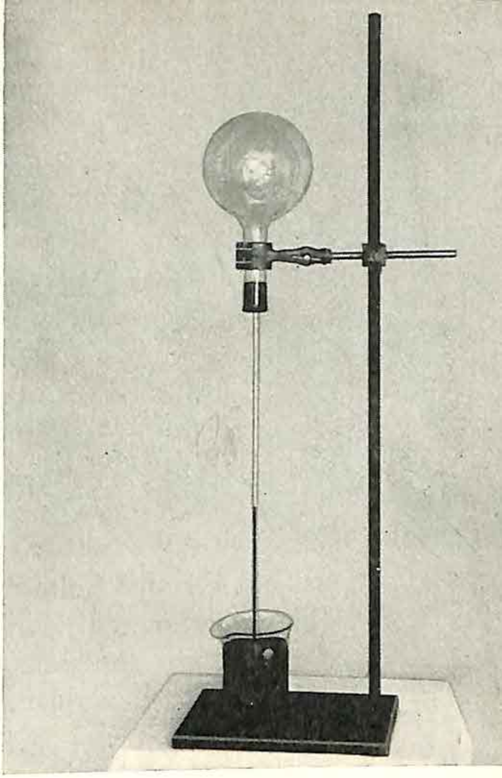


FIGURE 46. This is an air thermometer. It is extremely sensitive. The first thermometer invented by Galileo was made like this. Do you think it can always give accurate readings?

2. *To make a simple fire balloon.*

Cut out six large sheets of thin polythene and stick them together to form a balloon. Fix the open end of the neck to a ring and a small wire platform. With great care several hands can hold the balloon open whilst a bunsen burner is lit and inserted through the neck. The air is heated, expands, and becomes lighter. The cold air starts to push the balloon upwards. Turn out the bunsen and light some "meta" tablets fastened securely to the platform. Release the balloon outside in still air. Watch it rise steadily in the cold air. Be careful to do this in a place where you can follow its descent, because any small piece of burning "meta" that remains may easily cause a fire. Recover the balloon and ensure that no fire has been started.

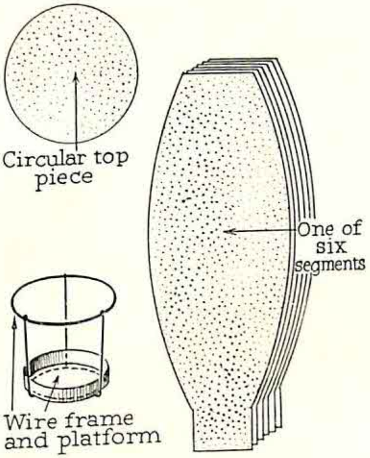


FIGURE 47. How to make a fire balloon. The diagram shows the shape of one segment, the circular top piece, and the platform.

Question 3. **What Use do we make of Expansion and Contraction ?**

Fortunately we can find many good uses for expansion and contraction. All substances exert enormous forces if one tries to stop them expanding or contracting. These forces are often used to tighten some things and to push others. We can mention only a few of the uses here but you will find many more as you look around.

The plates of a ship and the sheets of a boiler can be joined firmly together by *rivets*. The rivet is inserted red hot through holes opposite one another in the two plates, hammered flat, and then left to cool. As the rivet cools it contracts and presses the plates against one another as shown in Figure 48.

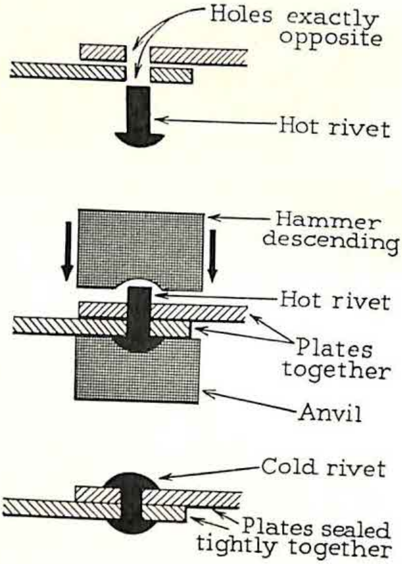
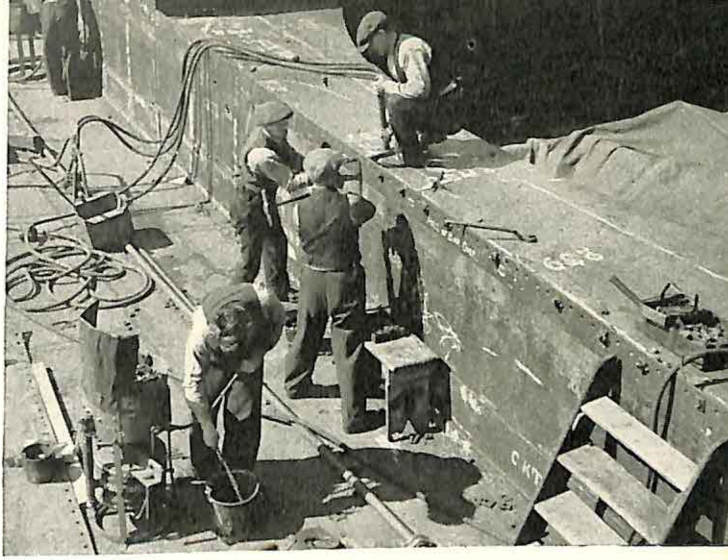


FIGURE 48. This shows how a rivet is put in place and hammered tight. Over a million rivets are needed for a big ship. No wonder shipyards can be noisy places to work in.



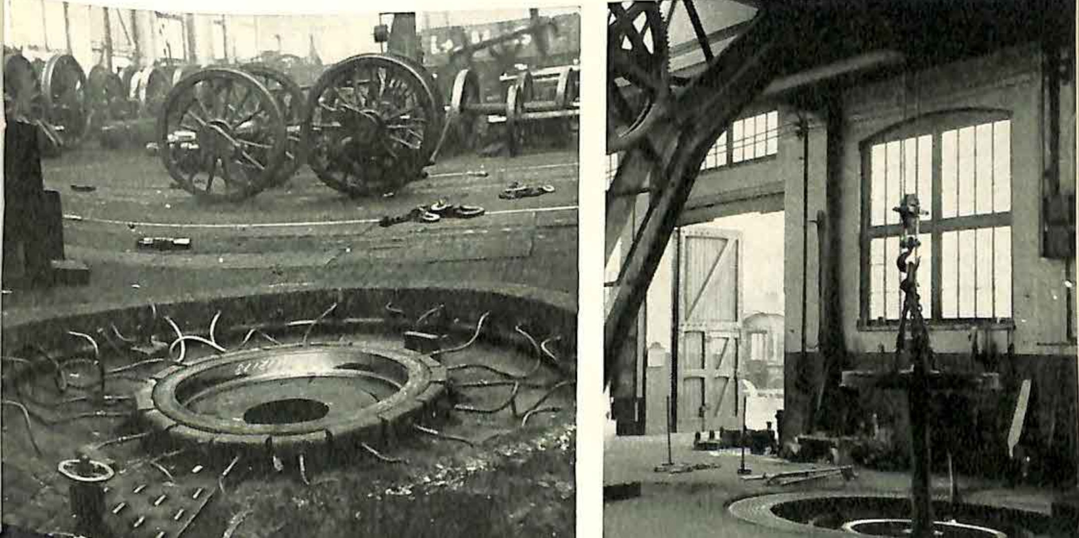
The Cunard Steamship Co. Ltd.

FIGURE 49. These men are riveting the sides of a new liner. You can see the man on the left is heating the rivets in a furnace, one man is putting the rivets in place, and two other men are hammering the hot rivets in the plates.

Steel tyres for locomotives and railway trucks are made so that they are just too small to fit when cold. When the tyre is heated all round it expands, and then the cold wheel is lowered into it and the tyre now just fits it. As the tyre cools it grips the wheel securely.

FIGURE 50. The left-hand photograph shows how a gas furnace is used to heat the steel tyre for the iron wheel. When the tyre has expanded sufficiently the cold wheel is lowered into position by means of the large crane shown in the right-hand photograph.

British Railways Western Region



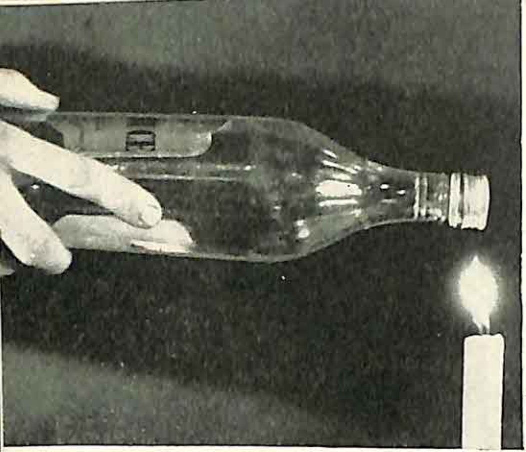


FIGURE 51. How to remove a tight-fitting metal cap from a bottle.

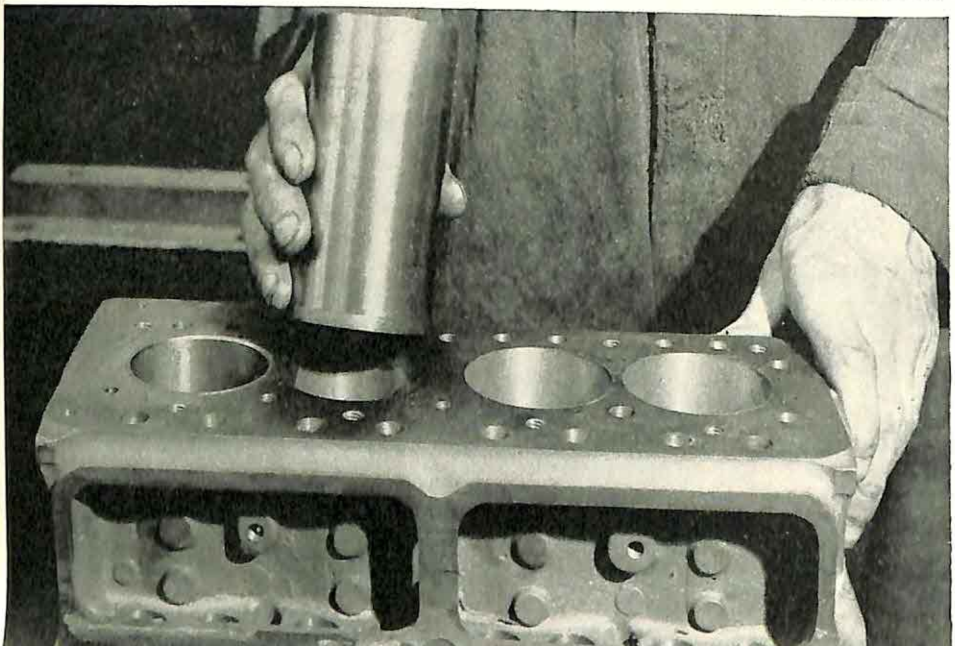
A glass stopper stuck tight in a glass bottle can be removed by heating the neck of the bottle either with a small flame or by rubbing it rapidly with a cord. In the same way a tight metal cap screwed on a glass bottle can be heated so that it expands and this makes it easier to remove.

A steel liner is inserted into an iron cylinder block of a petrol engine by cooling the liner in a refrigerator and then inserting it whilst cold. When cold it can just be pressed into position. As the liner warms it expands and is then always held firmly by the iron cylinder block.

Many refrigerators are switched on and off by the expansion and contraction of a gas enclosed in a sealed

FIGURE 52. This ice-cold steel liner is being placed in position over the hole bored in a warm cylinder block. The liner is fitted because it forms a smooth hard cylinder wall which will not wear away for a long time.

Morris Motors Ltd.



S.C.E.R.T., West Bengal
Library
Calcutta
25/3, B C

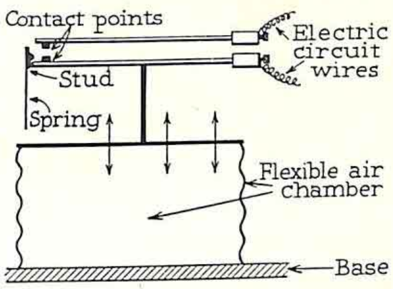


FIGURE 53. This diagram shows how a simple thermostat works The contact points are so mounted that they snap open or snap together. The projection on the stud causes the contact points to snap apart. Why would a slow movement spoil the contact points ?

tube. The movement of the gas causes a switch to snap open or closed. Such a device for keeping a temperature steady—a temperature-sensitive device—is called a *thermostat*.

The *bimetallic strip thermostat* is simple, robust, and cheap. The bending or curling movement, studied earlier in this problem, can be made to turn a suitable control on and off. For example, bimetallic strip thermostats are fitted to ovens, cookers, refrigerators, central heating and hot-water systems, and electric irons.

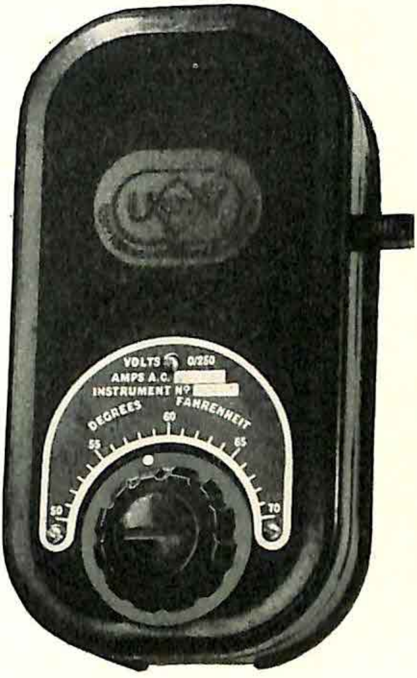


FIGURE 54. A thermostat mounted on the wall of a room to control the central heating installation. Can you see the knob which adjusts the average temperature ?

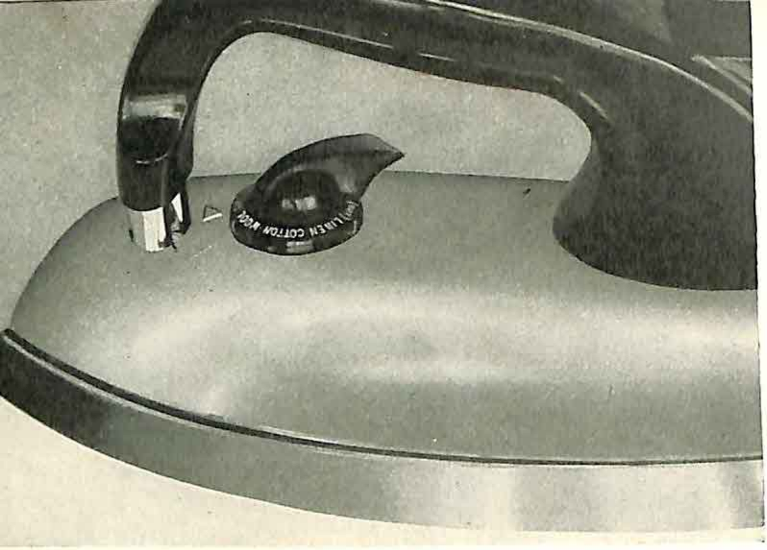


FIGURE 55. An electric domestic iron. Its temperature is controlled by a bimetallic strip thermostat. Note the insulated handle and the insulated indicator knob of the screw which adjusts the temperature. Why is a different setting of the temperature needed for different fabrics ?

Modern electric domestic irons like the one you can see in Figure 55 can be set to keep a steady temperature for ironing some particular fabric. The indicator knob has only to be twisted until it points to the correct setting. Figure 56 shows us how the bimetallic strip thermostat in the iron works. When the iron is cold and the current is switched on, it flows from the terminal T_1 through the flexible wire conductor, and the contact points to the bimetallic strip, and then to the heating

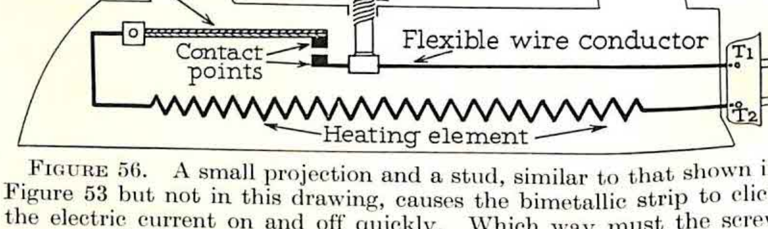


FIGURE 56. A small projection and a stud, similar to that shown in Figure 53 but not in this drawing, causes the bimetallic strip to click the electric current on and off quickly. Which way must the screw move the flexible conductor to make the iron hotter ?

element, and finally to the other terminal T_2. The element heats the iron and eventually, when the bimetallic strip is hot enough, it bends upwards with a jerk and opens the contact points which immediately stops the current. When the bimetallic strip has cooled down again, the contact points close together and the process is repeated. The indicator knob turns the screw which alters the position of the lower contact point. This causes the breaking of the contact points to occur earlier or later and thus the average temperature is set as desired for ironing any material.

Problem B : What is Temperature ? What are the Effects of Change of Temperature ?

Question 4. **How do we Compensate for unwanted Expansion and Contraction ?**

We have studied in the last question many examples where the forces of expansion and contraction have been used to help us. Unfortunately the expansion and contraction of substances sometimes cause us trouble and even danger, so we have to devise ways of avoiding these difficulties.

As a motor-car engine works, the temperature of the pistons rises more than that of the cylinders. Thus the expansions are unequal. That is why, when cold, the pistons are slightly smaller than the cylinders in which they move. When hot, the pistons fit well but not too tightly. Piston rings, which prevent the gases from leaking, are split to allow for expansion.

A steel alloy has been invented containing 36% of nickel. This alloy is called *invar* from the word "invariable," because it hardly expands at all on heating. A clock keeps accurate time if its pendulum is made of invar because it remains a constant length whatever the temperature.

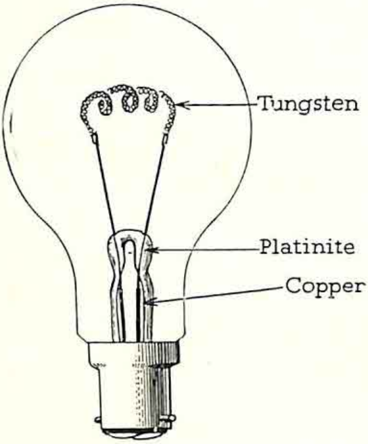


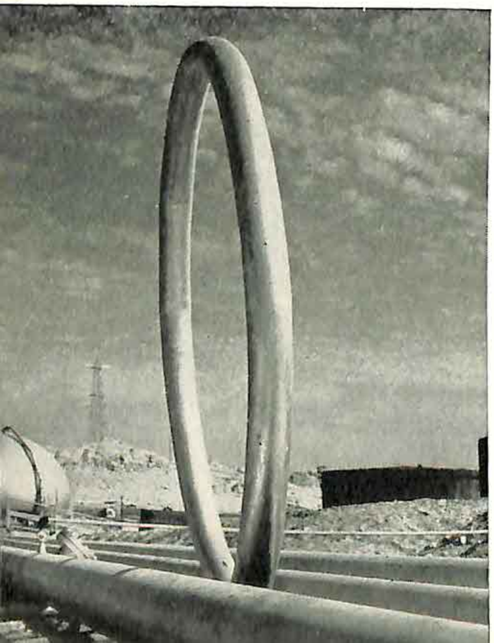
FIGURE 57. In this electric light bulb, can you see the copper wires from the contacts, the platinite, and the two straight copper supporting leads to the tungsten coiled coil filament ?

Another nickel steel alloy (45% nickel), called *platinite*, has the same rate of expansion as glass and is therefore used when a metal has to be fused into glass. As the temperature rises and falls, the glass and platinite expand and contract together so that there is no tension in the glass.

There are some cases where it is either too expensive or perhaps impossible to use materials which do not expand on heating.

Long pipes which carry steam and other hot liquids or gases have loops in them at regular intervals.

Long steel bridges like the Forth Bridge have to allow for an expansion of several feet. This can be done in many ways, for example, by mounting the ends on a "roller" bearing.



Arabian American Oil Company

FIGURE 58. This loop in one of the pipes carrying oil allows for the movement caused by expansion and contraction due to large temperature changes. The actual pipe which has this loop in it is hidden behind the bigger pipe nearer the camera.

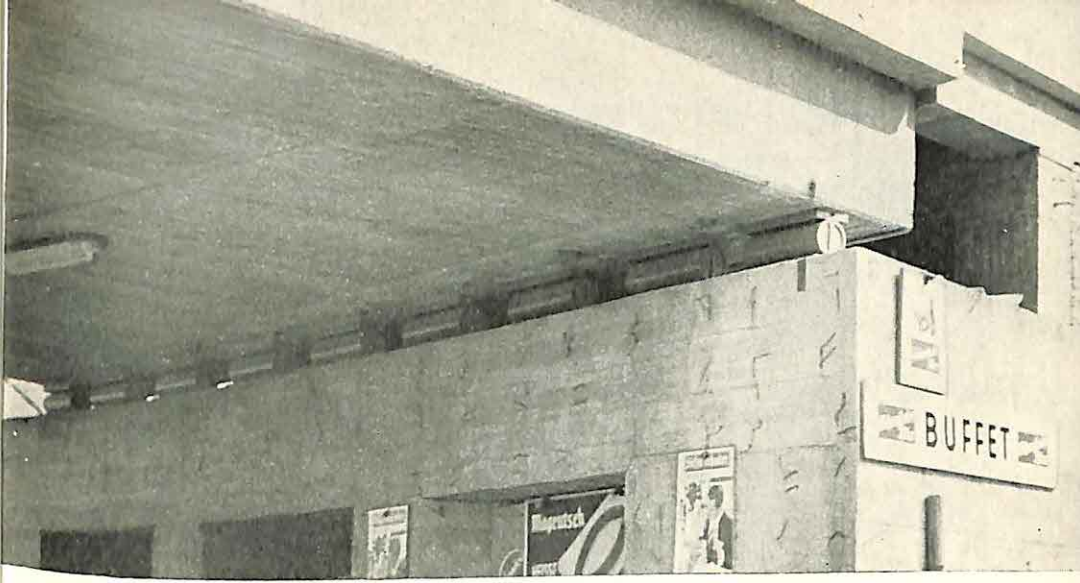
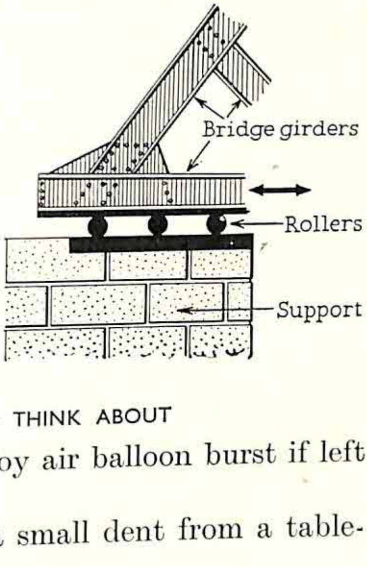


FIGURE 59. The drawing shows how a roller bearing works. The photograph above shows a number of rollers supporting a road bridge. Have you seen similar rollers on steel bridges or roof trusses ?



SOME THINGS TO THINK ABOUT

(1) Why does an inflated toy air balloon burst if left near a fire ?

(2) How can you remove a small dent from a table-tennis ball ?

(3) Why should well-inflated cycle and motor-car tyres not be left in the sunshine ?

(4) Why do sausages and potatoes burst when they are cooked in their skins ?

(5) Why do "trade" winds blow as they do ?

(6) Explain the movement of ocean currents.

(7) What part do you think the expansion of gases plays in an internal combustion engine ?

(8) Why is it dangerous to pour cold water into a motor-car radiator which has just boiled dry ?

(9) Why on hot days do ink fountain-pens that are nearly empty sometimes flood when you start to write with them ?

(10) Why do some tall skyscrapers lean towards the north at midday and towards the east in the afternoon ? Where could these skyscrapers be ?

(11) Two vacuum flasks are filled one with hot tea and the other with ice cream. They are left alone for a whole day. At the end of the day will it be easier or harder to take out the corks ?

(12) A motor-car radiator is filled to the top with water when cold. Why does the water leak away through the overflow as it warms up ?

(13) Why does "unseasoned" or "green" wood crackle when it burns ?

(14) Why do engineers who hang telephone wires in the summer time always leave them sagging between the poles ?

(15) How are iron rims put on wooden cart-wheels ?

(16) Why are the cracks between the concrete sections of a road filled with pitch ?

(17) Why is the mercury in a thermometer seen to drop before it rises when placed in hot water ?

(18) How does a "flasher" unit fitted to the winking lights of a motor-car work ? Is the same idea used in the "flasher" bulb of Christmas tree decorations ?

(19) How can a bimetallic strip be used to give warning of a fire in a building ?

(20) How is the temperature of the water in an electric water storage tank controlled ?

Problem C: HOW IS HEAT ENERGY MEASURED?

We have learnt what heat is, how it causes changes in some substances, and how we strive to retain it in some cases and get rid of it in others. In this Problem we shall consider how much heat is involved in *transfer*. For instance, how much heat do we obtain when we cool hot bodies? How much heat is needed to warm cold bodies? We have learnt how to measure temperature and now we must learn how to measure heat.

Problem C: How is Heat Energy Measured?

Question I. What is a Unit of Heat Energy?

Scientists throughout the world have agreed upon a standard unit of heat which is called a *calorie*. This unit is simply the amount of heat needed to raise the temperature of 1 gram of water through 1° C. We can find the amount of heat made available, for instance, by burning 1 gm. of paraffin in a suitable burner, or by consuming 1 gm. of sugar in the human body. Why do athletes and mountaineers often eat a form of sugar called glucose just before making a great physical effort? All the energy of animals is obtained from the food they consume. We can calculate the number of calories available in any meal we eat, and obviously a man doing hard manual labour needs more calories in his diet than a man sitting at a desk all day. We learnt in Problem A that it was Joule who first found the exact connection between work done and heat.

Let us find the number of calories needed to make the cold water in a kettle start to boil. Suppose there are 1,000 grams in the kettle and that it has a temperature of 15° C. Remember that water boils at 100° C.

1 gm. of water raised through
1° C. needs 1 calorie.
∴ 1,000 gm. of water raised through
1° C. need 1,000 calories.
∴ 1,000 gm. of water raised through
(100°–15°) = 85° C. need 85,000 calories.

∴ It requires 85,000 calories to bring the water in the kettle to boiling point.

In order to calculate problems of this kind multiply the weight of water measured in grams by the rise in temperature measured in degrees Centigrade. We can express this by an equation :

$$\begin{array}{c}\textbf{Heat}\\\textbf{Gained or Lost}\end{array} = \begin{array}{c}\textbf{Mass}\\\textbf{of Water}\end{array} \times \begin{array}{c}\textbf{Temperature}\\\textbf{Rise or Fall}\end{array}$$

or

$$\textbf{Heat} = \mathbf{M} \times (\mathbf{T}_1 - \mathbf{T}_2)$$

In English-speaking countries where weights are often measured in pounds and temperatures in degrees Fahrenheit, there still remains a special unit for measuring heat. It is the *British Thermal Unit* (B.Th.U.) and is the amount of heat needed to raise the temperature of 1 lb. of water 1° F.

When an engineer buys coal to burn in a furnace in order to heat water, he wants to know how much heat the coal will give. He expresses this by saying he will get from every pound of coal about 12,000 B.Th.U.s. When gas is sold to a customer its volume is measured in cubic feet. The number of B.Th.U.s of heat this represents is then calculated according to the heat-producing quality of the gas (i.e., the number of B.Th.U.s obtained from every cubic foot of gas). 100,000 B.Th.U.s are called a *therm*. The customer is charged a certain price for every therm he uses.

Question 2. **Do all Substances absorb Heat Equally ?**

This is an important question and we can find the answer by performing a simple experiment.

SOMETHING TO FIND OUT

Tie a piece of string to an iron 2 lb. weight. Weigh 2 lb. of water and pour it into a large saucepan. Put the weight in the water and heat the saucepan on a hot-plate until the water boils ; keep it boiling very slowly for about three minutes. Meanwhile prepare two polythene basins which will hold 4 lb. weight of

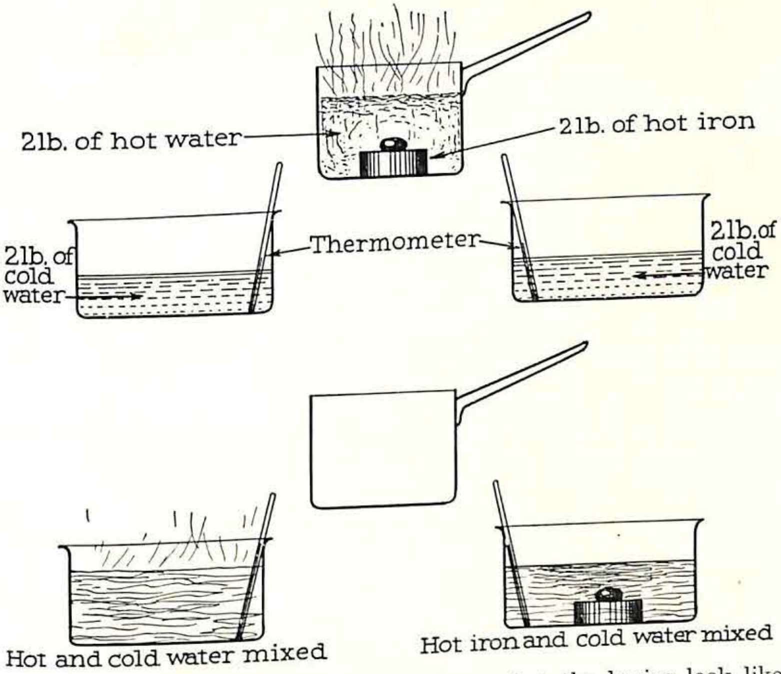


FIGURE 60. The drawings above show what the basins look like before mixing, and those below what they are like after mixing. Which has the greater heat to give out as it cools, the hot water or the iron weight ? Why are polythene basins used in this experiment ?

water with ease. Pour 2 lb. of cold water into each of the basins and suspend a thermometer in each. Now remove the hot iron weight from the saucepan and put it into one basin, and pour the 2 lb. of boiling water from the saucepan into the other basin. Observe the rise in temperature after about three minutes.

The boiling water will heat the water in its basin more than the iron weight will heat its water. Both the boiling water and the iron weight have the same mass and they both started at the same temperature (that of boiling water, 100° C.). We conclude from these facts that the boiling water carries over much more heat than the iron weight. In other words the water has absorbed more heat than the iron when they were heated together. This difference between the water and the iron is due to a property which we call the *specific heat*.

If we had performed this experiment carefully and calculated the exact number of calories [$M \times (T_1 - T_2)$] given to the water in both basins, we should have found that for every 1 calorie absorbed by the water only 0·11 calorie was absorbed by the iron. In other words it takes less than 1 calorie to make 1 gm. of iron 1° C. hotter. This value (0·11) is the specific heat of iron.

The table below gives the specific heats of a number of common substances.

Substance	Specific Heat	Substance	Specific Heat
Water	1·00	Lead	0·03
Iron	0·11	Paraffin	0·50
Copper . . .	0·09	Glass	0·19
Aluminium . .	0·20	Earth (soil) . .	0·20

Which of these eight substances requires least heat to raise its temperature by a fixed amount ?

Specific heats of substances vary greatly and water again turns out to be unusual. It has a specific heat which is the highest of all substances. Water takes longer to heat and longer to cool than any other substance because more heat change is involved. We use water in the cooling system of a motor-car because it can absorb large quantities of heat from the hot cylinders. Because of its high specific heat, water can be used to heat a bed—hence hot-water bottles: a block of iron of the same weight could not give out the same amount of heat.

The high specific heat of water explains also why the sea-shore is so welcome in very hot weather. The earth (specific heat 0·2) may become uncomfortably hot in the scorching heat of the midday sun, but the water (specific heat 1·0) by the seaside or in a lake takes longer to heat and so remains cooler. The hot earth

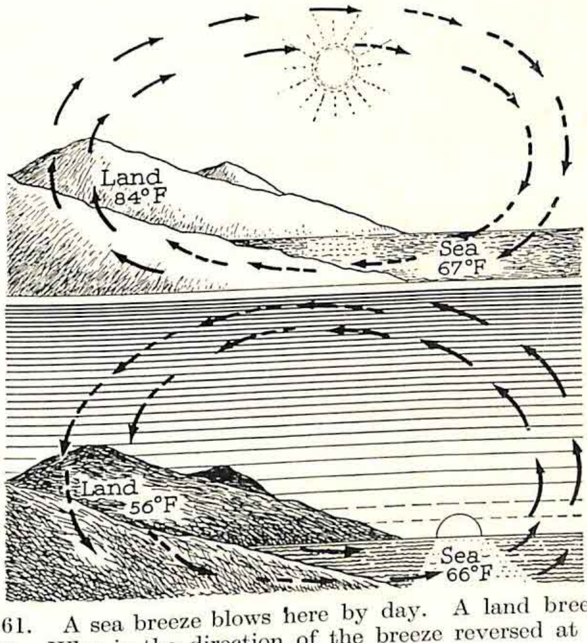


FIGURE 61. A sea breeze blows here by day. A land breeze blow by night. Why is the direction of the breeze reversed at night?

during the day heats the air immediately above it much more than the cooler sea is able to heat the air above the sea. This means that the cooler air from the sea blows in across the sea-shore and replaces the warmer lighter air over the land. These cool sea breezes at the seaside make very hot days more comfortable. During the night the breeze blows in the opposite direction because the land has less heat to lose than the sea and therefore cools more rapidly.

People in Asia or North America who live hundreds of miles away from the nearest ocean experience a great range of temperature. We describe their climate in geography as " continental," they have extremely hot summer months and extremely cold winter months ; this is because the specific heat of the earth's crust is small and thus the earth heats up quickly in summer and soon loses its heat in winter. Those who live on or near large areas of water find a cooler climate in summer and a warmer climate in winter because the specific heat of water is large.

Degrees Fahrenheit in	GLASGOW	MOSCOW
JANUARY	39°	14°
JULY	58°	66°

Compare the average summer and winter temperatures in Glasgow and Moscow. These two towns have almost the same latitude. Can you find another pair of towns with an equally striking difference in average temperatures and yet having almost the same latitudes ?

Warm ocean currents travel a long way. Follow in your atlas the track of the Gulf Stream, from the seas around the West Indies where the hot tropical suns heat the ocean, along the coast of North America, across the Atlantic Ocean and round the North Cape in Europe. Warm water from such a current keeps much of its heat even though it drifts for hundreds of miles over colder waters. Transatlantic passengers from Britain to North America notice a sudden change of temperature as their ship travels into and again when it leaves the Gulf Stream. You now know that the high specific heat of water is partly responsible for winters in Britain being less cold than they would be if there were no Gulf Stream.

Problem C : How is Heat Energy Measured ?

Question 3. What Happens when Hot and Cold Substances are brought together ?

We have learnt that there are three factors which determine the quantity of heat (calories or B.Th.U.s) given out or absorbed by a body when its temperature changes. These are (1) the mass of the body, (2) the rise or fall in temperature, and (3) the nature of the material of which the body is composed. If the body is water of specific heat 1 then :

$$\underset{\text{(in calories)}}{\text{Quantity of heat}} = \underset{\text{(in grams)}}{\text{Mass}} \times \underset{\text{(in degrees C.)}}{\text{Temperature change}}$$

But if the body is made of another substance like iron of specific heat 0·11, the quantity of heat is less. So that we can write for all bodies :

$$\underset{\textit{(in calories)}}{\textbf{Quantity of Heat}} = \underset{\textit{(in grams)}}{\textbf{Mass of Body}} \times \underset{\textit{(in degrees C.)}}{\textbf{Temperature Change}} \times \underset{\textit{(a number)}}{\textbf{Specific Heat}}$$

In the last question we studied what happened when a hot iron weight was brought into contact with cold water in a basin. The heat given out by the hot iron weight was used to warm the cold water and eventually both the iron and the water reached the same temperature. Except for a very little heat lost to the surrounding air and the basin *the heat lost by the hot body equals the heat gained by the cold body.*

All bodies brought and left together eventually exchange heat until they have a common temperature.

Let us apply these equations to a simple problem. Suppose you have put in a bath 10 buckets of water at 70° C. and you wish to bath in this water. You would find it too painful to get into a bath of water as hot as 70° C. How many buckets of cold water at 15° C. should you add to bring the water after mixing to a suitable temperature of 40° C. ? Assume that no heat is lost elsewhere and that you pour in x buckets. We then have these equations :

Heat gained by the cold water you pour in = Heat lost by the hot water already in the bath

or

$$\underset{\textit{(for the cold water)}}{M \times (T_1 - T_2) \times \text{Sp. Ht.}} = \underset{\textit{(for the hot water)}}{M \times (T_1 - T_2) \times \text{Sp. Ht.}}$$

$$\text{or } \underset{\textit{(buckets)}}{x} \times \underset{\textit{(° C.)}}{(40 - 15)} \times 1 = \underset{\textit{(buckets)}}{10} \times \underset{\textit{(° C.)}}{(70 - 40)} \times 1$$

$$\therefore 25x = 10 \times 30$$

$$\therefore x = 12$$

Thus you must pour in 12 buckets of cold water.

SOME THINGS TO THINK ABOUT

(1) It requires 75 kilograms of water for a bath. The cold water from the mains comes into the house at 15° C. and the warm bath water from the boiler is supplied at 40° C. How many calories are needed to warm the cold water for a bath ?

(2) Why is there a temperate climate in Britain whereas very much colder temperatures occur in winter on

the coasts of Labrador although they are further than Britain from the North Pole ?

(3) Ethylene glycol has a specific heat of 0·57. It freezes at − 17° C. and boils at 197° C. Can you think of two reasons why glycol is used in the radiators of aircraft engines ?

(4) You can dry your hands without burning them by placing them in a current of hot air. Why would it be dangerous to put your hands in water at the same temperature ?

Problem D : **WHAT ARE THE THREE STATES OF MATTER ?**

We generally think of water as being a *liquid*. We mean, of course, that at ordinary temperatures it is a liquid. An Eskimo thinks of the same substance as a *solid* and does not consider it as frozen water. We are both correct, for ice can be changed to water by heating, and water can be changed to ice by cooling. We are both talking of the same substance in two differing *states*. When water is boiled, it changes into a third state—*steam*, which is a *vapour*. So this is an example of one substance existing in three states. Because each of its states is very common each state has its own name : ice (a solid), water (a liquid), and steam (a vapour).

Usually we speak of the solid, liquid, and gaseous forms of some substance. The gas carbon dioxide, for instance, can be changed into a liquid and even into a solid. You may have seen some solid carbon dioxide in the cabinet of an ice-cream seller. It is white, like snow, and is often called " dry ice " (Fig. 63). You may wonder why steam is called a vapour and carbon dioxide a gas when they are both similar in many ways —it is because a vapour freely and easily turns to a

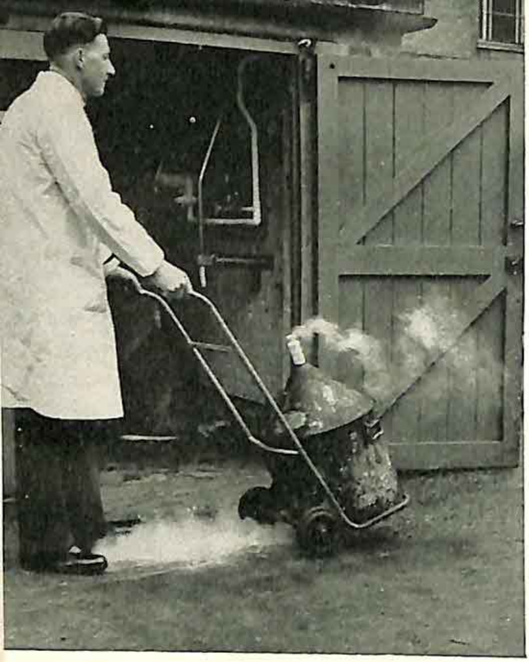
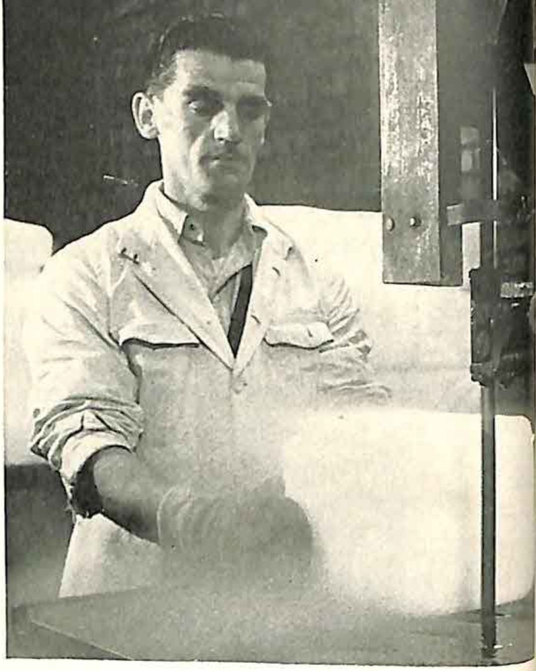


FIGURE 62. This man is pushing on his truck a large vacuum flask of liquid oxygen. What is the white vapour you can see near the mouth of the flask? Some of the liquid oxygen has spilled on the floor and is being converted into oxygen gas.

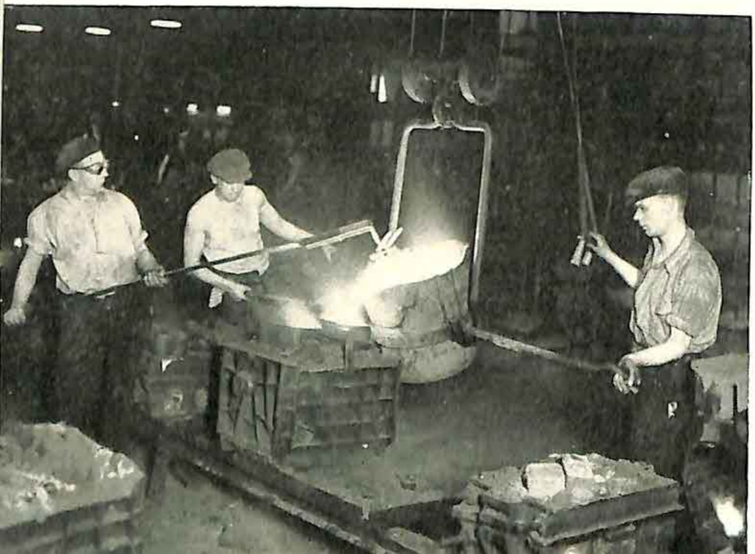


I.C.I. Ltd.

FIGURE 63. Blocks of solid carbon dioxide. Why is the man wearing gloves? Why is there a mist around the block the man is about to cut?

liquid, whilst it is sometimes difficult to make a gas turn to a liquid.

We usually think of iron as a solid, but it can be turned into a liquid in a furnace at about 1,600° C. and can then be poured into moulds where it will set

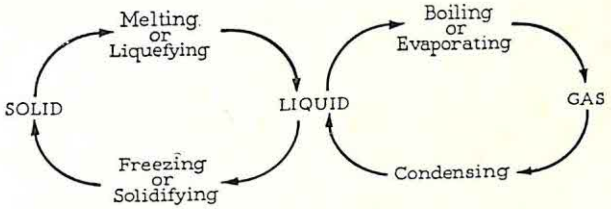


Morris Motors Ltd.

FIGURE 64. These men are pouring liquid iron into moulds. This is very hot work. Why do these men keep their shirts on at work?

in the same way that a jelly will set in a mould.

We should be quite clear of the words we use when a substance changes from one state to another and back again. To understand them look at this diagram :

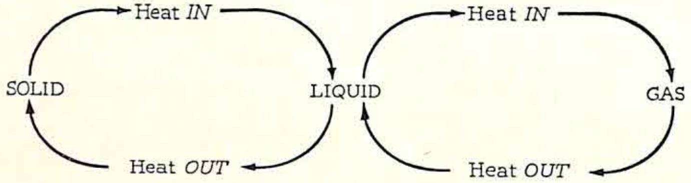


Freezing applies to water and ice. Boiling is more vigorous than evaporation and takes place throughout the whole of the liquid, not just on the surface where evaporation occurs.

The change which takes place when a substance turns from a solid to a liquid, or turns from a liquid to a vapour or gas, requires the taking in or absorption of heat. You have to supply heat to bring about the change from solid to liquid to gas (as in the case of the iron furnace). Sometimes the change may take place through the substance taking the needed heat from its surroundings (as in the case of the solid carbon dioxide in the ice-cream seller's cabinet).

When the reverse processes take place and a substance turns from gas to liquid, or from liquid to solid, heat is given out. For instance, as steam condenses to water it gives out an enormous amount of heat. That is why it is much more dangerous to be scalded by steam than by boiling water. Water does not easily turn to ice—in Britain it takes several days of cold weather below the freezing point of water (0° C. or 32° F.) for a pond or a lake to lose enough heat to freeze over, and many more days before the ice is thick enough for skating. A large quantity of heat has to be lost by the water before it becomes ice.

So remember that in all changes of physical state, large quantities of heat are given off or absorbed during the actual change.



Problem D : What are the Three States of Matter ?

Question 1. **What Happens when a Solid turns to a Liquid ?**

There are three things to consider when a change of state takes place. They are the change of heat, of temperature, and of volume.

To help us to understand what happens when physical changes of state occur, we can observe some experiments using ice, water, and steam. The same effects apply to other substances, but the quantities of heat involved and the temperatures at which changes take place are different.

SOMETHING TO FIND OUT

Fill a tin can with chips of ice and insert a thermometer in the can. Is the temperature of the ice 0° C. ? Add some warm water and stir the mixture. Watch the thermometer carefully and note the temperature. Now transfer the tin can to a stand and heat it gently with a small flame. Continue to stir the mixture thoroughly and observe the temperature every 15 seconds. Does the temperature change before the last piece of ice is melted ?

We might expect the temperature of the mixture to rise as it is slowly heated—*but that does not happen.* The flame steadily gives heat to the mixture. Where is the heat from the flame going? It is melting the ice, for that is the only change taking place. When there is no more ice to melt, then the temperature starts to rise in the way we expected. Heat is absorbed by the ice as it turns to water. There is *a change of heat*. We say that the heat is "hidden" because our thermometer cannot detect any rise in temperature. Scientists call this *latent heat*, because "latent" means "hidden." In fact, this experiment tells us that a liquid contains more heat than the solid from which it came although they may both be at the same temperature.

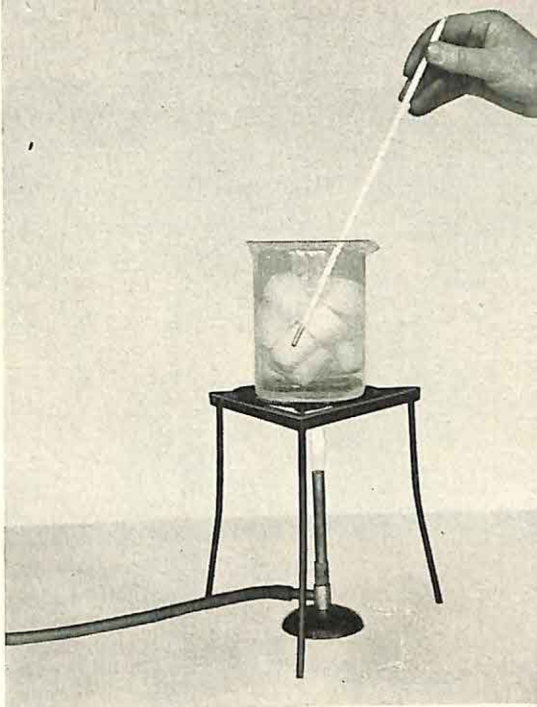


FIGURE 65. A glass beaker has been used instead of a tin can so that the melting of the ice can be observed. When does the temperature start to rise?

The experiment also tells us something about the *temperature* at which ice melts. Ice has a definite melting point (0° C.), and this does not vary during the whole of the physical change from solid to liquid.

British Iron and Steel Federation

FIGURE 66. A large mechanical press shaping bars of red-hot steel. The steel remains hot long enough for much work to be done on it.

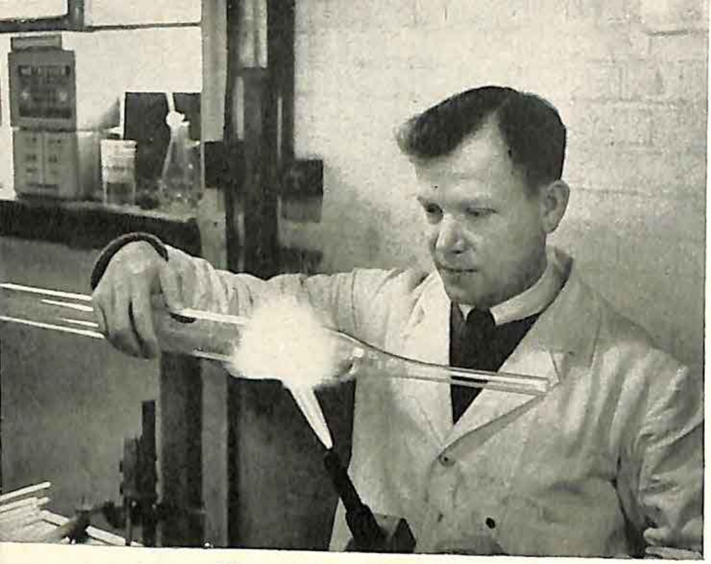
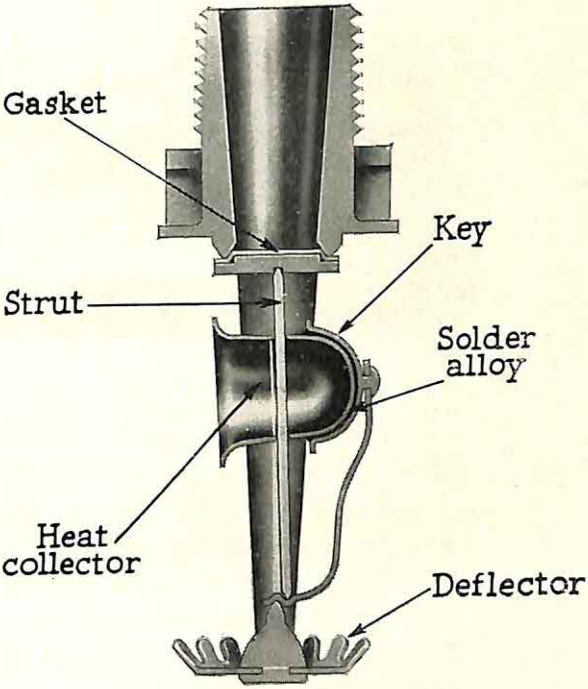


FIGURE 67.—This man is a skilled glass-blower. He heats the glass in a gas flame until it becomes soft enough to blow into any desired shape. The hotter the glass becomes the more it begins to "run" as a liquid. He can seal pieces together and mould the glass into delicate and complicated patterns.

Elements and pure compounds have a definite sharp melting point, but some mixtures do not. For example, tar, pitch, glass, and wrought iron become soft and melt over a range of several degrees rise in temperature. This is fortunate because it enables us to manipulate glass, for example, to blow it and to bend it whilst it is neither a true solid nor a true liquid. It enables a smith to beat wrought iron when it is in a molten state and thus shape iron gates and horseshoes.

The use we can make of some materials depends on their melting points. The alloy called Wood's metal has a melting point of 65° C.—it will melt in a cup of hot tea! There are several alloys of bismuth with lead, tin, and cadmium which have very *low melting points*. Such alloys are sometimes used in automatic fire alarms and automatic water sprinkler systems. The heat from an accidental fire in a building melts the metal which then completes an electric alarm circuit and releases a jet of water from a nozzle.



Mather and Platt Ltd.

FIGURE 68. A cross-section of a water sprinkler. The soft metal gasket is held in position by the strut until the alloy between the heat collector and the key melts. When this happens the water pressure in the pipe above pushes everything aside and throws a jet of water against the deflector below. This forms a fine spray which is spread around to put out the fire. Why are these sprinklers put on the ceilings and not on the walls or floors?

The heat produced by an excessive current in an electric circuit may cause damage by fire. So a fuse wire is included in the circuit. The fuse wire is made of an alloy of tin and lead and has a lower melting point than the copper wires in the rest of the circuit. The fuse wire melts and thus breaks the circuit when the current exceeds a certain value.

Materials with *high melting points* have their uses also. Tungsten has the highest melting point of all the metals, 3,380° C., and thus is used to make the filaments of electric lamps.

No ordinary fire can burn through iron (melting point: 1,500° C.) or through steel (melting point: 1,400° C.). It requires the very hot oxy-acetylene flame to melt these metals. That is why fire doors, fire escapes and safes are built of iron and steel.

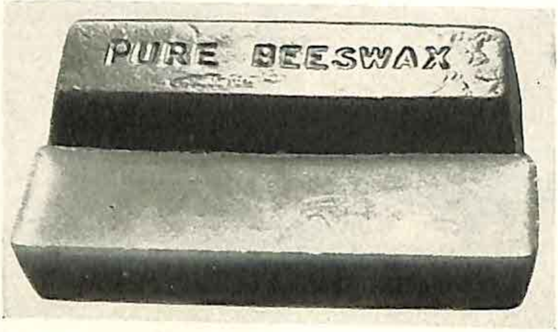


FIGURE 69. These are blocks of pure beeswax. Do you notice the hollows and imperfections in the mouldings ?

A change of state from solid to liquid in most cases means a *change in volume* as well as a gain in latent heat. Most substances expand as they melt.

Gold, silver, and wax are some of the many substances which expand on melting and contract on solidifying. This is why gold and silver coins cannot be cast in moulds : they have to be stamped out. Beeswax also does not take the shape of a mould exactly and always has a hollow in the middle of its surface as it sets.

Water is an exception because it contracts on melting and this is important as we shall learn in the next Question.

SOMETHING YOU MAY CARE TO DO

Take six similar tin lids and place in each lid the same weight of one of these substances—lead, solder, sulphur, paraffin wax, sealing wax, and water. Freeze the water in its lid. Now put each lid in turn over a small flame of a burner and keep away from draughts. Observe the time taken from the commencement to the end of the process of melting. Do these times tell you something about the latent heats of these substances ? Which substance has the greatest latent heat and which the least ?

Question 2. **What Happens when a Liquid turns to a Solid ?**

All the *changes of heat* which occur when a solid turns to a liquid are reversed when a liquid turns to a solid. The amount of latent heat absorbed when a solid turns to a liquid is given out again as the liquid turns back to a solid.

Freezing is the reverse of melting, and the freezing point of water is the same as the melting point of ice.

The ranges of *temperature* at which substances solidify are the same as those observed when the same substances melt.

Impurities can change the *temperature* at which pure liquids solidify.

How do impurities in water change its freezing point? Pure water freezes at 0° C. When a solution is made by dissolving in water a substance such as salt, sugar, acid, alcohol, or glycerine, it is found that the solution has a freezing point lower than that of pure water. This explains why salt is spread on icy pavements and roads—it lowers the freezing point below air temperature so that the mixture becomes liquid. A motorist adds anti-freeze to the water in the radiator of his car to prevent the water freezing in cold weather. The more anti-freeze he adds the lower is the temperature at which the solution freezes. The sulphuric acid in the battery of the car is a solution which freezes at about − 30° C.

A *change in volume* occurs when solidification takes place. Most substances contract. We have already mentioned this in the case of gold, silver, and wax. There are many other substances which contract in the same way when changing from a liquid to a solid.

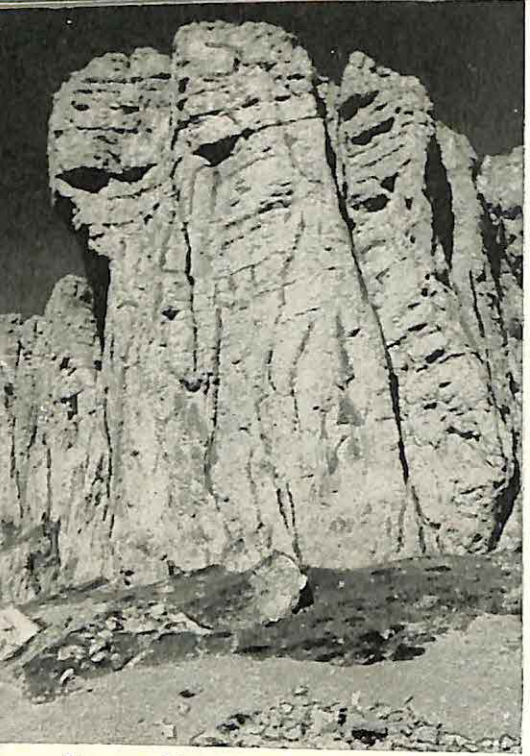
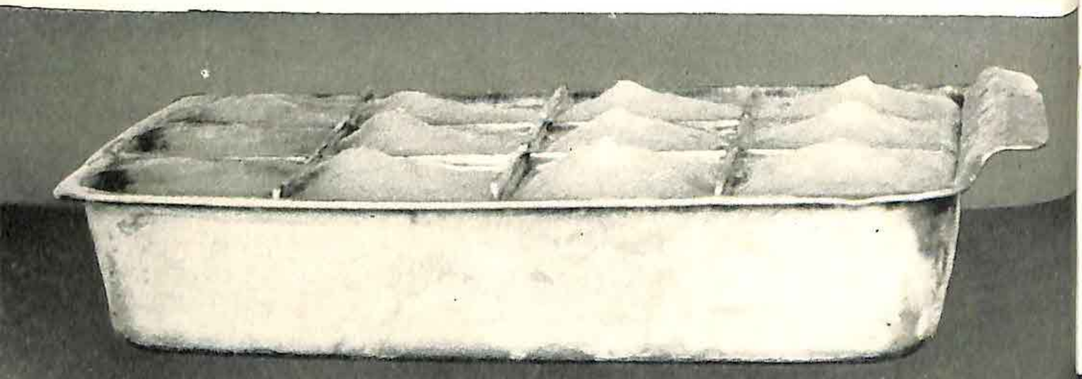


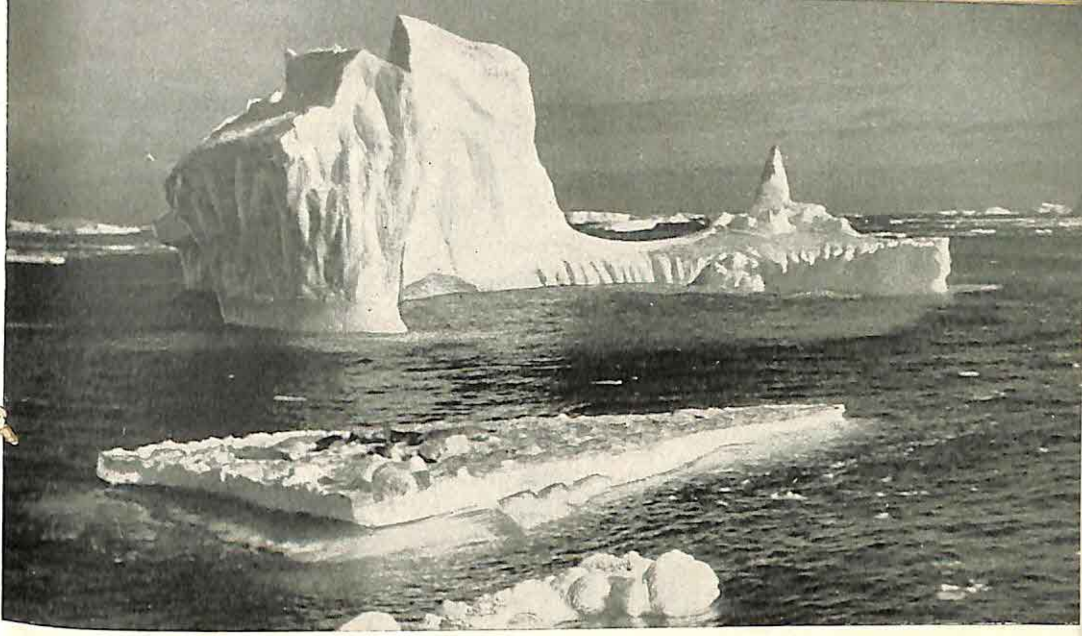
FIGURE 70. Water runs into cracks in these rocks during the day. In the night the water freezes, expands, and splits off large blocks of stone, as you can see by examining this photograph.

Iron and type-metal are two of the substances which *expand* on solidifying. That is why these two substances can be made into good castings. A hollow mould is prepared and the molten liquid metal is poured in until it is full. As the metal solidifies it expands and takes the exact shape of the mould, filling every little space.

Water also is an exception because it expands when it freezes. If there is no room for the water to expand it creates a tremendous force. This force bursts water pipes and motor-car engine blocks if they are not properly protected during a frost; it breaks rocks to pieces in a process called *weathering*; it cracks concrete roads if the water can find its way under them; it helps the gardener and farmer by smashing to pieces the clods of earth.

FIGURE 71. Why are there humps on these cubes of ice in this tray which has just been taken out of a refrigerator?





Polar Photos Ltd.

FIGURE 72. An iceberg off the Newfoundland banks. Why do ships keep well clear of icebergs ?

Because of this expansion on freezing, ice is less dense than water and it therefore floats on water. Icebergs drift for a long way in the oceans before they melt and they have about nine-tenths of their volume below the surface and only about one-tenth above the surface. It is not surprising that ships crossing the North Atlantic Ocean steer a more southerly course in spring in order to avoid the icebergs drifting south from the Arctic Sea.

SOME THINGS YOU MAY CARE TO DO

1. Fill a fruit juice bottle to the neck with cold water and fasten the cap on firmly. Place the bottle in a bucket of a freezing mixture made from ice and salt. Leave it for some time. How do you explain what happens to the bottle ?

2. Melt some wax and some type-metal and put each in a separate deep narrow mould like a thimble. Make some jelly and leave it in a deep basin. Allow them all to set and examine the surfaces of the solids formed. Which expands and which contracts on solidifying ?

Problem D : What are the Three States of Matter ?

Question 3. **What happens when a Liquid turns to a Gas ?**

There are, as in the process of melting, three things to consider when this change of state takes place.

The *change of heat.* In order to change a given volume of a liquid to a gas a large quantity of heat is required. We have seen that when a solid melts heat is absorbed as the change takes place without any rise in the temperature of the solid. The same is true when a liquid boils. Again we say that this heat is " latent " but they are not the same in quantity. The latent heat needed to melt a given weight of ice is much less than the latent heat needed to boil the same weight of water to steam.

The *temperature* or boiling point of most substances under normal conditions is definite and does not vary during this change of state. If you are trying to identify a substance, it is often helpful to find its boiling point.

An impurity in a liquid causes its boiling point to alter. For instance, when salt is added to water it boils at a higher temperature. Usually the more impurity in the liquid, the greater the change in the boiling point. Do you know that an egg will " cook " more rapidly by boiling it in salt water than in ordinary water ?

The *change in volume* which takes place when a substance boils is considerable. The small particles of which the substance is composed move about rapidly and occupy as much space as they can. The liquid which may have been contained in a small vessel becomes a gas which spreads out into space and may, if not carefully confined in some way, disappear altogether from the immediate neighbourhood. There is no limit to the volume a gas may occupy.

Problem D : What are the Three States of Matter ?

Question 4. **Can a Liquid turn to a Gas without Boiling ?**

The physical change from the liquid to the gaseous state goes on at all temperatures by the slow process of *evaporation*. The waters of the oceans, lakes, and rivers slowly evaporate. Whereas melting usually takes place at a fixed temperature evaporation occurs at every temperature. As the temperature rises the rate of evaporation increases until the liquid evaporates throughout the whole body of the liquid, or in other words until it boils.

The *rate of evaporation* depends on :

(*a*) *The area of the exposed surface.* A wet sheet dries quicker if it is opened out on a drying line than when it is left folded.

(*b*) *The nature of the liquid.* Ether, alcohol, and petrol evaporate much more rapidly and oil much less rapidly than water. Put a few drops of petrol, water, and oil on your hand. You will soon observe the different rates of evaporation. Which drop feels the colder as they all evaporate ?

(*c*) *The temperature of the liquid.* Wet clothes dry faster on a warm day than on a cold day, all other conditions being equal.

(*d*) *The rate at which the vapour is removed.* Wet clothes dry faster on a windy cold day than on a calm cold day.

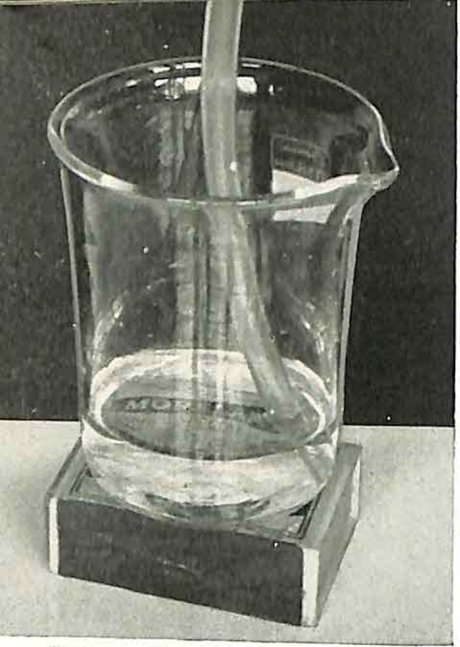


FIGURE 73. Why should you use only a small depth of ether for this experiment ? (A glass beaker is used here instead of a tin can.) Why does ether poured on your hand feel very cold when it is blown?

SOMETHING YOU MAY CARE TO DO

To observe the cooling effect of evaporation. Make a small pool of water on a match-box. Stand in the pool of water a tin can containing a small quantity of ether to a depth of about $\frac{1}{8}''$. Blow some air by means of a drawn-out glass tube through the ether. After a short time the water freezes. Can you separate the tin can and the match-box ? Where has the latent heat given out by the water turning to ice gone ?

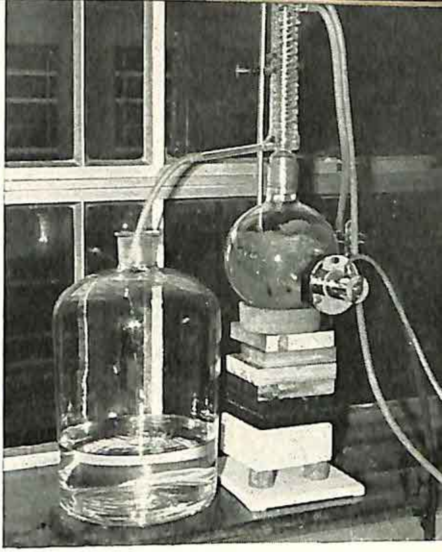
Question 5. **What Happens when a Gas turns to a Liquid ?**

This is the reverse of evaporation. If a kettle is left boiling in a closed room the water vapour will turn to liquid water on cold windows. This process is known as *condensation*. The latent heat gained during evaporation is given out during condensation. The process takes place slowly over a wide range of temperatures.

What is distillation ?

This is the process of boiling a liquid and condensing its vapour. It is used to separate the parts of a solution by boiling one part away and condensing this part while leaving the other parts behind. Petroleum is distilled to give petrol, paraffin, fuel oil, and many

FIGURE 74. This is an electric water still. Water is boiled by an electric immersion heater in the flask (boiler) standing on the wooden blocks. The steam produced is condensed by a stream of cold water flowing through a glass spiral in the wide glass tube (condenser). The condensed steam or distilled water pours over and is collected in the receiver shown on the left in the photograph.



other products. Water is distilled to produce pure water for accumulators and chemical experiments.

SOMETHING YOU MAY CARE TO DO

Put 3 or 4 dry cubes of ice in a tin can. Under the can place a steady flame and note the time. As the cubes melt stir them in the water formed and again note the time when the last piece of ice melts. Take two more readings of the time, one when the water begins to boil and the final one when the tin can is completely dry. You can assume that the flame has supplied heat at the same rate all the time. Record your observations in this way:

Time taken by the flame to supply:

(1) The latent heat needed to change ice to water = ... seconds.

(2) The heat needed to change water from 0° C. to 100° C. = ... seconds.

(3) The latent heat needed to change water to steam = ... seconds.

Does this show that the latent heat of melting of ice is nearly that needed to raise water from 0° C. to 100° C.? Does it show that the latent heat of vaporization of water is more than five times as great as the latent heat of liquefaction of ice?

We now realize why a scald caused by steam in condensing to water is much worse than one caused by boiling water—in fact more than five times as bad.

When liquids are evaporating instead of boiling, this large latent heat is still needed and if it is not supplied by a flame the heat must be taken from the surroundings. That is why when ether or petrol evaporates on your hand it feels cold, and if you blow air against your hand to hasten evaporation it feels colder still.

Problem D: What are the Three States of Matter?

Question 6. **Can Pressure affect the Melting Point or Boiling Point?**

The best way of answering this question is to perform a few simple experiments and to observe the results.

Can the melting point of a solid be changed by pressure?

SOME THINGS YOU MAY CARE TO DO

1. Press two blocks of ice against one another in a vice. Do the jaws of the vice rapidly make impressions on the ends of the ice blocks? Why should the jaws of a metal vice be covered with pieces of wood before this experiment? Does water appear at the junction between the two blocks of ice (look carefully for this)?

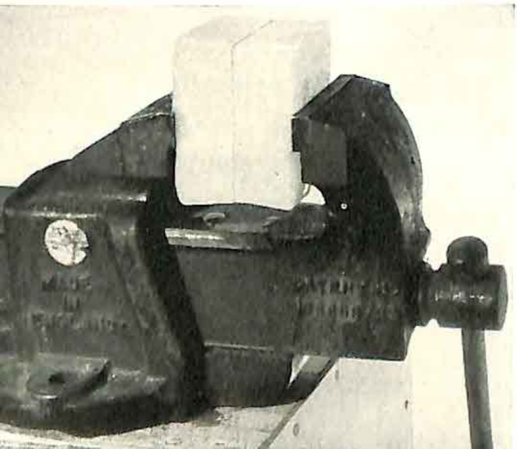


FIGURE 75. These two blocks of ice are formed into one block under pressure in a vice. Can you exert enough pressure with your hands to seal two ice cubes together?

Release the pressure. Can you separate the two ice blocks? Has the ice turned to water as a direct result of the application of pressure? Does this mean that the melting point of ice has been lowered by pressure?

2. Place a copper wire over a large lump of ice and hang a heavy weight on both ends of the wire. Does the wire slowly cut through the ice? Does the ice seal over again where it has been cut through? Why does this happen?

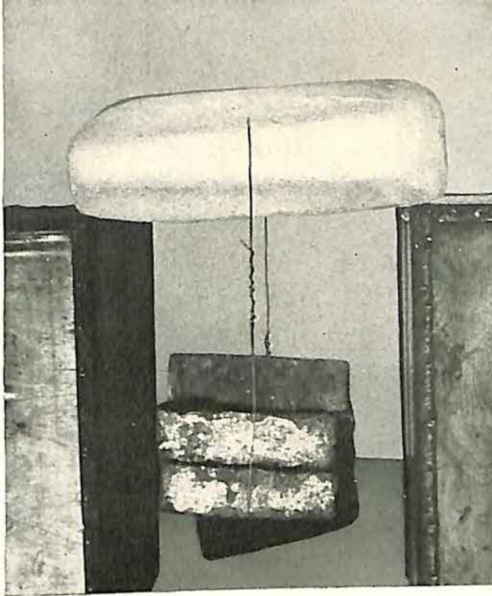
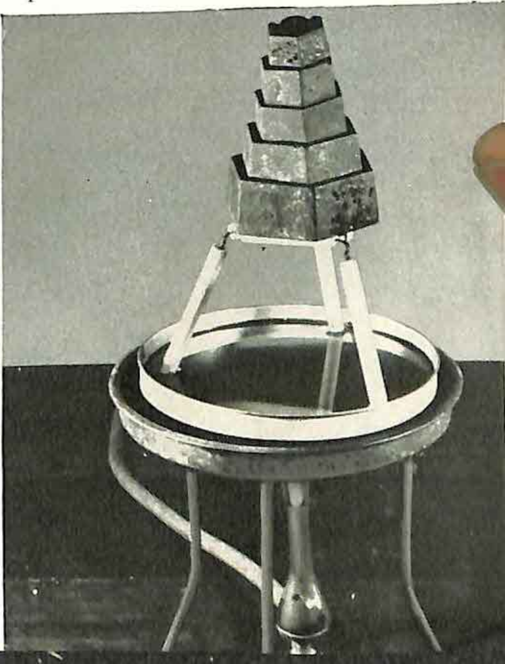


FIGURE 76. Ice turns to water and back again to ice. Can you hasten the process by hanging on bigger weights? It is the process by which a glacier, or river of ice, slowly flows downhill.

3. Pour a very thin layer of molten paraffin wax into a shallow cake tin and leave the wax some time to set solid. Fasten three wooden dowel rods so that they lengthen the legs of a small tripod. Stand it on the surface of the wax in the cake tin. Put the cake tin over a dish of hot water and place a heavy weight on the tripod. Wood is a bad conductor of heat so almost no heat is transferred. Is there wax unmelted under the legs of the dowel rods when all the other wax has melted? Does this mean that the melting

FIGURE 77. Why do small areas of unmelted wax remain under the legs of the tripod?



point of wax has been raised by pressure ? Compare this result with the result of the first experiment.

Other substances behave in similar ways. Substances that expand as they solidify (like water) have their melting points lowered by external pressure. Substances that contract on solidification (like wax) have their melting points raised.

A skater moves easily over the surface of ice. The weight of the skater on the ice lowers the melting point of the ice. The ice under the skate melts and forms water which acts as a lubricant. Hence the skater really skates on water not on ice, and as soon as he moves along the pressure is released from the water and it freezes again. Is this what happened when the copper wire cut through the lump of ice described in experiment 2 ?

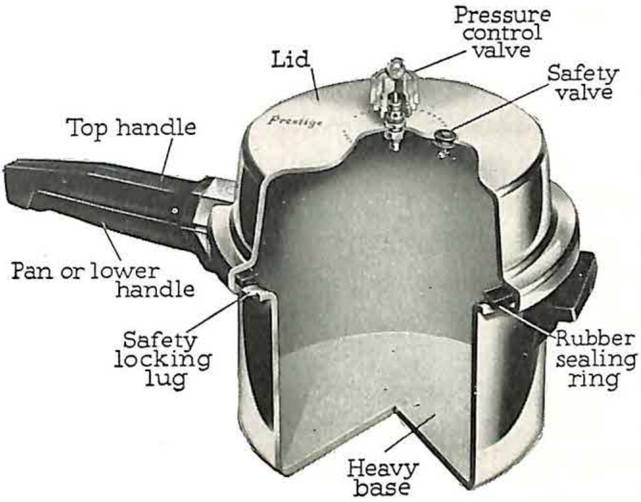
What is the effect of a change of pressure on the boiling point of water ?

Decrease of pressure lowers the boiling point, and increase of pressure raises the boiling point.

Those who live on high mountains know well that potatoes and other vegetables cannot be cooked properly in the boiling water there. Tea cannot be brewed or an egg boiled satisfactorily at very high altitudes. On the top of Mont Blanc, the highest mountain in Europe, water boils at 85° C. whereas at sea-level it boils, as you know, at 100° C. At these heights, or to speed cooking at any height, a pressure cooker can be used.

FIGURE 78. These skaters perform their graceful movements on thin layers of water beneath their skates.

Swiss National Tourist Office



The Prestige Group Limited

FIGURE 79. A food pressure cooker. Notice the strong body and lid. Why is a safety-valve fitted in the lid ? How are different pressures controlled in the cooker when in use ? What device seals the lid to the body of the cooker ?

Pressure cookers have a lid which can be fastened down securely to retain the steam escaping from the liquid. The resulting steam pressure causes the boiling point to rise. Potatoes will cook at these pressures and temperatures in less than 10 minutes. The pressure in steam boilers is often so great that the water boils in them at 150° C. The steam at this high temperature and large pressure is most effective when used in steam engines or turbines.

Problem D : What are the Three States of Matter ?

Question 7. **What Uses can be made of Changes of State ?**

Our health and comfort depend to a large extent upon keeping our bodies at an even temperature. As we run about, climb hills, or do other hard work, we " burn " large stores of food in the body and produce excessive heat. In cold weather much of this heat is transferred to the cold air but in warm weather we need some additional means of cooling ourselves. This is provided by perspiration—small drops of moisture passing out through the pores of the skin. The drops of perspiration evaporate and take in latent heat from the body and thus the body is cooled. On very hot days we perspire a lot and need plenty of water to drink. We can increase the rate of evaporation of perspiration by putting ourselves in a draught of air, as for instance in front of a fan.

In some countries where it is very hot, people cool their houses by making water evaporate rapidly. They hang up a kind of sacking in the entrance and throw water on it. They keep water in large porous earthenware jars because some of the water always seeps slowly through the walls to moisten the outside of the jar. There the moisture evaporates, keeping the jar and the remaining water cool.

SOMETHING YOU MAY CARE TO DO

Take two plates and on each put a small quantity of butter. Over one plate invert a clean earthenware plant pot which has been soaked in cold water. From time to time moisten the plant pot again. After several hours in a warm room try to cut the butter on each plate. Which has remained cool and why ?

Refrigerators

Many foods go bad if left in the ordinary air of a larder, which is usually warm enough for bacteria and moulds to multiply. Many years ago, scientists discovered that the commonest bacteria and moulds cannot multiply if the food is kept at a low temperature.

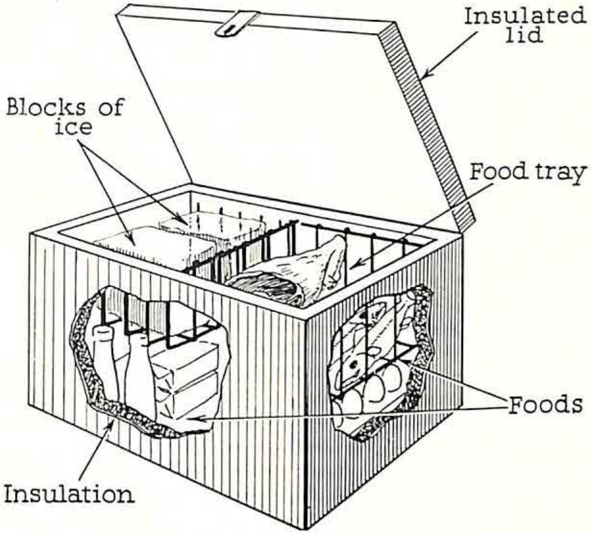


FIGURE 80. Ice box refrigerator. Why is the ice placed in a cage at the top of the food compartment ? Why is it better to have a lid which opens upwards than to have doors which open on one side ? Sections of the front and side walls have been cut away so that it is possible to see inside.

A few degrees above the freezing point of water is usually sufficient. So today some form of *refrigerator* is an important article in many houses and shops.

There are several kinds of refrigerator, but all of them contain some sort of freezing unit at the top. The air in the refrigerator around the freezing unit is cooled and circulates round the food compartments by convection currents. The heat in the foods is absorbed by the cold air. The cold air thus becomes warmer and rises to the top of the refrigerator. Here it is cooled all over again by the freezing unit, which may be a block of ice as in Figure 80 or a number of coiled pipes through which heat is transferred from inside to outside the refrigerator. The block of ice will melt in due course and must be replaced, but the freezing unit can be kept cold if some machine worked by electricity,

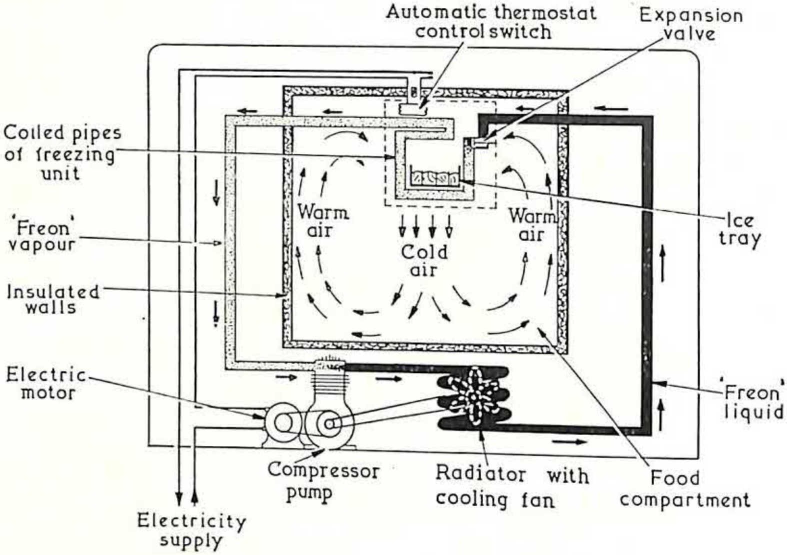


FIGURE 81. Electric refrigerator. A liquid, "Freon," is pumped through the expansion valve where it turns to a vapour in the coiled pipes of the freezing unit. Why do the coiled pipes become very cold? Why does ice soon form on these pipes so that "defrosting" is necessary? Why is it desirable to leave plenty of air space behind the cooling fan blowing on to the radiator?

gas, or oil transfers heat from it to a radiator outside the cold food compartment.

Frozen meat, fish, fruits, vegetables, and other foods are familiar to most of us. These products are processed by "quick freezing" at about − 30° C. which turns the water of the liquids in the cells of these foods into small ice crystals.

"Slow freezing" turns the water into large ice crystals which break the fine tissues and cell walls. Thus foods which have been frozen slowly lose their fine taste and become soggy.

Quick frozen foods can be kept for a long time and after slow thawing taste just the same as the fresh foods, but they must not be allowed to thaw and refreeze during storage.

This method of food preservation is now replacing the older methods of canning, pickling, and salting.

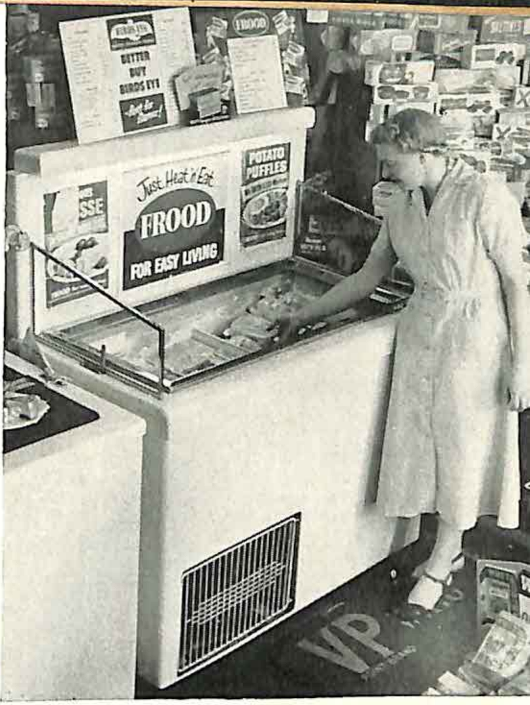


FIGURE 82. A "deep freeze" food cabinet. This one is installed in a shop. Why is it not necessary to have a lid to close it during shopping hours ?

Air-conditioners

Great use is made today of air-conditioning plants. Our health, comfort, and vitality depend to a large extent on the condition of the air in the house or building where we spend much of our time.

An air-conditioner is fixed in such a way that air can be drawn through it from outside and blown into the building. Dust, dirt, bacteria, pollen, and unpleasant odours in the air are removed by filters, water sprays, or wet cloths and then the air is heated or cooled according to the outside weather conditions. Moisture is added as the air is heated in winter months, and removed as it is cooled in summer months so that the air finally delivered by the plant is neither too dry nor too damp.

Air-conditioning controls the temperature, amount

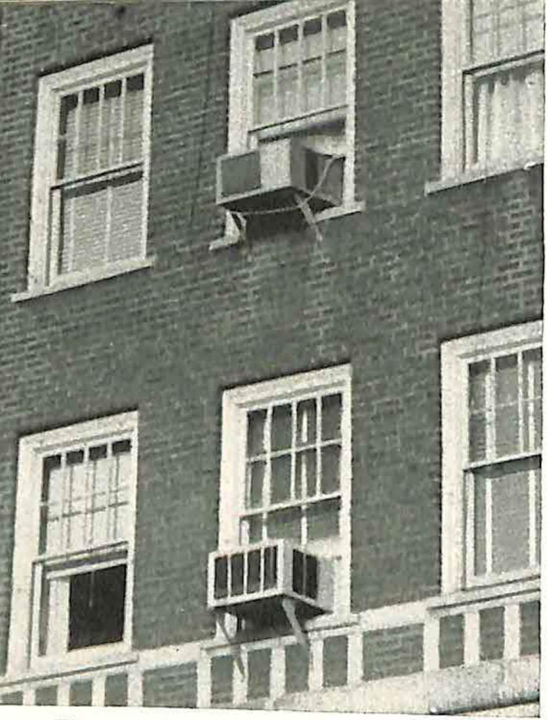


FIGURE 83. Two of the windows in this block of flats are fitted with outside air-conditioners. Air is collected, cleaned, warmed or cooled, and then pumped inside the building.

of moisture, cleanliness, and circulation of the air.

The best temperature for the air in a house depends on many factors—the season of the year, the amount of clothing worn, and the age and vitality of the people living in the house. In winter 68° F. is a comfortable temperature; in summer 78° F. is usually very pleasant.

The amount of moisture present in the air is an important condition. When there is too much we feel tired, we lack vitality, and perspiration clings to the body; and if this happens in winter some of the moisture condenses making everything damp, even the walls and windows. If there is too little moisture in the air the skin is dry and tends to crack, and the throat feels dry and uncomfortable. Living is only really pleasant when the amount of moisture present in the air, or what is called the *humidity*, is somewhere between these two extremes.

The circulation of the air in a room or house must also have attention. Air must circulate and at the same time there must be a certain exchange of air between indoors and outdoors in order to remove stale air and bring in a continuous supply of oxygen for breathing. Windows open at the top and bottom can produce a good circulation. An electric fan can be used to circulate the air by blowing out the stale air, or by mixing the warm air below the ceiling with the cold air near the floor.

The use of these air-conditioning plants makes life more pleasant in every climate but for those who live in tropical areas it is almost a necessity. Installed in houses, public buildings, trains, ships, coaches, and aircraft they make it possible to have refreshing sleep, to work longer hours without fatigue, and to travel in comfort in conditions of intense heat or cold.

SOME THINGS TO THINK ABOUT

(1) After a severe winter, why does it take a long time in the spring to melt the ice on a lake ?

(2) Why does a farmer do all his ploughing before the winter comes ?

(3) How do we prevent the frost in winter from breaking the concrete surface of a road ?

(4) Why do icebergs drift such a long way in the oceans before they melt away ?

(5) A pond has been completely frozen over in the winter. Why do cracks suddenly appear across the pond ? Why do we find all the stones disturbed at the water's edge after the ice has melted away in the spring ?

(6) Why is there often a column of frozen milk standing on the top of the neck of a milk bottle left outdoors in freezing weather ?

(7) What causes so many rocks to fall off mountains in the summer and roll down into the valleys ?

(8) Why do large tubs of water placed in a storage cellar help to prevent vegetables and fruit from freezing in cold weather ?

(9) Why does a refrigerator tray for making ice cubes not burst when in use ?

(10) Why is it impossible to form snowballs on a very cold day ?

(11) If the ice of an indoor skating rink is considerably below 0° C., why do skates sometimes fail to "bite" ?

(12) How can glaciers flow down curved valleys ?

(13) Why can flowers live for a long period in a block of ice ? Why can some plants and animals remain buried in snow all winter and yet come to life again in the spring ?

(14) When camping in hot weather, why is it a good idea to keep water in a canvas bag ?

(15) The story is told of a Scot who turned his plaid inside out after a shower of rain because he did not wish to feel the cold as he walked home through the wind. Why was this action wise ?

(16) Why does a person sitting in front of an electric fan on a hot humid day feel cooler than when sitting in the same room without a fan ?

(17) When steam is passed into cold water, why do you hear a series of loud cracks ?

(18) Why on a windy day do roads dry quicker after a rainstorm ?

(19) A skater finds it easy to move on ice because his skates are lubricated underneath by a thin layer of water. Does the same thing take place under a pair of skis ?

(20) Why are steam radiators smaller than hot-water radiators which give off the same quantity of heat ?

Heat is one of the many forms of _energy_.

There is always a fixed quantity of heat equivalent to a fixed amount of energy. This relationship is *Joule's equivalent.*

Heat is *transferred* in three ways :

conduction—from particle to particle in the body,
convection—by the movement of the particles of a liquid or gas,
radiation—through space without the need for any material in the space.

Surfaces which are *good radiators* are *good absorbers* of radiation.
Surfaces which are *poor radiators* are *poor absorbers* of radiation.

Buildings are heated by *convectors* and *radiators.*

The _temperature_ of a body determines the _direction_ in which heat will flow between it and its surroundings.

Heat travels from a body at a higher temperature to one at a lower temperature.

Temperature is measured by a *thermometer* in *degrees* on a *scale.*

Temperature of :	Fahrenheit	Centigrade
Boiling water	212	100
Blood (human)	98·6	37
Melting ice	32	0

$$\frac{F - 32}{C} = \frac{9}{5}$$

Solids, liquids, and gases *expand* when heated and *contract* when cooled.

Expansion and *contraction* can help us, as in the thermostat, but at other times they are a nuisance and we have to compensate for them.

Invar is an alloy with an extremely small expansion.

1 *calorie* is the quantity of heat needed to raise the temperature of 1 gram of water through 1° C.

Quantity of Heat gained or lost = Mass of substance × Temperature change × Specific heat

or $Q = M \times (T_1 - T_2) \times S$

$$\text{SOLID} \rightarrow \left.\begin{array}{l}\text{Heated.}\\ \text{Melts or}\\ \text{Liquefies}\end{array}\right\} \rightarrow \quad \text{LIQUID} \quad \rightarrow \left.\begin{array}{l}\text{Heated.}\\ \text{Evaporates}\\ \text{or Boils}\end{array}\right\} \rightarrow \text{GAS}$$

$$\text{SOLID} \leftarrow \left\{\begin{array}{l}\text{Cooled.}\\ \text{Freezes or}\\ \text{Solidifies}\end{array}\right. \leftarrow \quad \text{LIQUID} \quad \leftarrow \left\{\begin{array}{l}\text{Cooled.}\\ \\ \text{Condenses}\end{array}\right. \quad \leftarrow \text{GAS}$$

The three states of water:

Ice (*Solid*); Water (*Liquid*); Steam (*Vapour*).

Most substances expand on liquefying, e.g. gold, silver, wax.
Some substances contract on liquefying, e.g. iron, type-metal, water.

Evaporation takes place only on the surface of a liquid as it turns to a gas or vapour.

Boiling takes place both on the surface and in the body of a liquid as it turns to a gas or vapour.

Distillation is the process of boiling and condensation.

Increase of pressure *lowers* the melting point of substances that *expand* on solidification.
Increase of pressure *raises* the melting point of substances that *contract* on solidification.

Increase of pressure *raises* the boiling point of liquids.
Decrease of pressure *lowers* the boiling point of liquids.

Impurities in water alter both its freezing point and its boiling point.

S.C.E.R.T., West Bengal
Library

530
HEA

SCIENCE ON THE MARCH

125

The Air and You
Water and Life
The Weather and the Earth
Life and Food
Health
Energy and Engines
Hearing and Seeing
Electric Currents
Magnets and Electric Power
Earth and Universe
Heating and Cooling
Birth and Growth
Metals and Man

1724
LONGMANS